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Microcomputer Program for Daily Weather Simulation in the Contiguous United States

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Abstract

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The microcomputer program USCLIMAT.BAS provides precipitation probabilities and simulates data for daily precipitation, maximum temperature, minimum temperature, and solar radiation for an n-year period at a given location within the contiguous United States. The model is designed to preserve the dependence in time, the internal correlation, and the seasonal characteristics that exist in actual weather data. Daily maximum temperature, minimum temperature, and solar radiation data are simulated using a weakly stationary generating process conditioned on the precipitation process described by a Markov chain-mixed exponential model. Parameters for specific stations within a region can be accessed directly, or they can be estimated for points between stations. The seasonal variations of parameters are described by the Fourier series. Information on the type of equipment needed to run the model and an example of running the model are provided.

KEYWORDS: climate, Markov chain, microcomputer, precipitation, probability, simulation, solar radiation, temperature, weather

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Contents

Notations

c_{ik}	Amplitude of the kth harmonic of a Fourier series. Describes the probability of a transition from a dry day to a dry day or a wet day to a dry day
C_j	Amplitude of the first harmonic for Fourier series representation of the mean or coefficient of variation of t_{max}, t_{min}, and r
$C_j(n)$	Coefficient of variation of t_{max}, t_{min}, and r on day n
E { }	Expected value (mean)
F_m	Cumulative distribution function in m days
i	Subscript representing a dry day (i=0) or a wet day (i=1)
inf	Infimum (smallest)
j	Subscript representing t_{max} (j=1), t_{min} (j=2), or r (j=3)
M	Number of years
M_0	3 by 3 matrix of lag 0 correlation coefficients between t_{max}, t_{min}, and r
M_1	3 by 3 matrix of lag 1 correlation coefficients between t_{max}, t_{min}, and r
m_i	Maximum number of harmonics in the Fourier series describing the probability of a transition from a dry or wet day to a dry day
n	The day number (from 1 to 365)
N (m)	Number of wet days in an m-day period
$p_{00}(n)$	Probability of a transition from a dry day on day n−1 to a dry day on day n

$p_{01}(n)$	Probability of a transition from a dry day on day $n-1$ to a wet day on day n
$p_{10}(n)$	Probability of a transition from a wet day on day $n-1$ to a dry day on day n
$p_{11}(n)$	Probability of a transition from a wet day on day $n-1$ to a wet day on day n
$\bar{p}_{i0}$	Annual mean probability of a transition
r	Daily solar radiation (Langleys)
r_1, r_2	Normally distributed random variables with mean = 0 and standard deviation = 1
$S(m)$	Total precipitation in m days (inches)
$s_j(n)$	Standard deviation of t_{max}, t_{min}, or radiation on day n
T	Daily precipitation threshold (inches)
$t_j(n)$	Daily value of t_{max}, t_{min}, or radiation
t_{max}	Daily maximum temperature (°F)
t_{min}	Daily minimum temperature (°F)
u_1, u_2	Uniformly distributed random variables on the interval (0, 1)
$u_j(n)$	Mean or coefficient of variation of the Fourier series for t_{max}, t_{min}, and r on day n
$\bar{u}_j$	Annual mean of the Fourier series for t_{max}, t_{min}, and r
$X_\tau(n)$	Random variable having a value of 1 when day n of year τ is wet and 0 when it is dry

y	Observed precipitation (inches)
y'	Observed precipitation minus the threshold, T (inches)
$Y(n)$	Precipitation depth on day n (inches)
$\alpha(n)$	Weighting factor in the mixed exponential distribution for day n
$\beta(n)$	Mean of the smaller exponential distribution for day n (inches)
$\delta(n)$	Mean of the larger exponential distribution for day n (inches)
$\epsilon_j(n)$	Normally distributed error term for t_{max}, t_{min}, or radiation for day n
θ_{ik}	Phase angle in radians for the kth harmonic of a Fourier series. Describes the probability of a transition from a dry day or a wet day to a dry day
λ	Mean of exponential distribution
$\mu(n)$	Mean of the precipitation greater than threshold T for day n (inches)
$\mu_j(n)$	Mean of t_{max}, t_{min}, or radiation for day n
$\chi_j(n)$	Vector of normalized residuals $[t_j(n)-\mu_j(n)]/s_j(n)$
$\psi_0(m, k)$	Probability that there are k wet days in an m-day period given that the prior day was dry
$\psi_1(m, k)$	Probability that there are k wet days in an m-day period given that the prior day was wet

Introduction

Climate and day-to-day variations in weather have major influences on agricultural and engineering management decisions. Crop yields, insect infestations, proper rangeland stocking rates, and hydrological processes such as runoff and erosion are all highly weather dependent. Weather data to assess the effects of climate on agricultural and rangeland activities are needed as inputs to management models. For many sites, climatic records are of insufficient length for making the desired agricultural or engineering analyses. Therefore, it is often desirable to have the capability to generate climatic data that have the appropriate statistical characteristics for the location.

The extensive weather data gathered by the National Weather Service are available on magnetic tapes (some are now available on diskettes and CD–ROM for microcomputer use). These data, however, are somewhat cumbersome to use. The information content of the data can be summarized by statistical analyses and the results presented in tabular or graphical form. Results of extensive analyses performed by the regional climate committees of the state agricultural experiment stations during 1955–67 were presented in a series of reports (Shaw et al. 1960, Dethier and McGuire 1961, Feyerherm et al. 1965, Gifford et al. 1967). Recent developments in microcomputer technology and lower costs of microcomputers have made new systems feasible for the analysis of climatic information.

In this report we describe USCLIMAT.BAS (an updated version of the microcomputer program CLIMATE.BAS in Woolhiser et al. 1988), which provides easy access to precipitation probabilities or simulated daily weather data for a location within a state or region. Daily climatic data, including data for February 29th (in a leap year), can be simulated with USCLIMAT.BAS for most locations within the contiguous United States from the user's response to instructions that are displayed on the screen. After the user enters the latitude and longitude of an area of interest into the computer, the computer will construct a regional grid map on the screen that includes state boundaries and any of 360 climate stations located within the region. Parameters for generating climate data for each station are stored in two disk files. Maps for obtaining the parameters required to generate daily maximum and minimum temperature data and for generating solar radiation data are given in the appendix. The maps in the appendix were made because the climatic generation procedures in CLIMATE.BAS, which were obtained from a model called WGEN (Richardson and Wright 1984), do not generate accurate minimum temperature data or solar radiation data in some instances. (The CLIMATE.BAS model does not generate good data for minimum temperatures in the northern latitudes; it also generates inaccurate solar radiation data for wet days in northern latitudes and for dry days in areas such as southern Arizona.)

Daily precipitation is described by a first-order Markov chain with precipitation amounts distributed as a mixed exponential. In addition, data on daily maximum and minimum temperatures and on solar radiation are simulated using a weakly stationary generating process first described by Matalas (1967) and adapted to daily weather by Richardson (1981). The seasonal variations of parameters are described by Fourier series providing a very parsimonious model. Through the interactive microcomputer program, a user can access the information for a single station or can estimate weather characteristics for points between stations through a simple interpolation procedure.

This program is designed to supplement, not replace, actual climatic and weather data. One advantage of the simulation approach described here is that it doesn't require a great deal of computer memory or data storage capacity and can be used on rather modest microcomputer systems. Another advantage is that solar radiation can be estimated for locations where it has not been measured.

Finally, the interpolation procedures of the program are advantageous because they allow estimates of daily weather characteristics at points between weather stations.

The objective of this manual is to provide sufficient technical information so that the user can understand the assumptions of the model and the procedures of the model's data analyses and can see an example of running USCLIMAT.BAS.

Estimation of Precipitation

Occurrence of Daily Precipitation

The occurrence or nonoccurrence of precipitation on day n of year τ is represented in the model by the random variable $X_\tau(n)$; $\tau=1, 2, \ldots M$; $n=1, 2, \ldots 365$; as follows:

$$X_\tau(n) = \begin{cases} 0 \text{ if precipitation did not occur on day n} \\ 1 \text{ if precipitation occurred on day n.} \end{cases} \quad [1]$$

The dependence between wet and dry occurrences on successive days is described in the model by a seasonally varying first-order Markov chain with transition probabilities $p_{ij}(n)$; $i=0,1$; $j=0,1$; as follows:

$$p_{ij}(n)=P\{X_\tau(n)=j \mid X_\tau(n-1)=i\} \text{ for } n>1 \text{ and}$$
$$p_{ij}(1)=P\{X_\tau(1)=j \mid X_{\tau-1}(365)=i\}. \quad [2]$$

Since the remainder of this precipitation section concentrates on just 1 year, we will drop the subscript $_\tau$ from further discussion. Because $p_{i1}(n)=1-p_{i0}(n)$, only two parameters are required for each day. Seasonal variations are accounted for in the model by expressing the transition probabilities as a Fourier series as follows:

$$p_{i0}(n)=\bar{p}_{i0}+\sum_{k=1}^{m_i} c_{ik}\sin(2\pi nk/365+\Theta_{ik}); \; n=1,2, \ldots 365, \quad [3]$$

where $i=0$ or 1, m_i is the maximum number of harmonics required to describe the seasonal variability of the transition probability, $\bar{p}_{i0}$ is the annual mean value of the parameter, c_{ik} is the amplitude, and Θ_{ik} is the phase angle in radians for the kth harmonic. The means, amplitudes, and phase angles are estimated by numerical optimization of the log likelihood function; this estimation procedure is described by Woolhiser and Pegram (1979) and Roldan and Woolhiser (1982). Fourier series representations of parameters in a first-order Markov chain for precipitation have been used (among others) by Feyerherm and Bark (1965), who used least squares techniques for parameter estimation, and by Stern and Coe (1984), who formulated the estimation problem as a generalized linear model to obtain maximum likelihood estimators.

The unconditional probability of day n being wet is approximated in the model by the following expression:

$$P\{X(n)=1\} \approx [1-p_{00}(n)]/[1+p_{10}(n)-p_{00}(n)]. \quad [4]$$

Distribution of Daily Precipitation

On wet days daily precipitation amounts above a threshold, T, are described in the model by the mixed exponential distribution (from Smith and Schreiber 1974) as follows:

$$f_n(y') = \frac{\alpha(n)\exp[-y'/\beta(n)]}{\beta(n)} + \frac{[1-\alpha(n)]\exp[-y'/\delta(n)]}{\delta(n)} \qquad [5]$$

where $y'=y-T$, the daily precipitation amount minus a threshold, T, provided $y>T$; $\alpha(n)$ is a weighting parameter with values between 0 and 1; and β (n) and $\delta(n)$ are the means of the smaller and the larger exponential distributions, respectively. Let $\mu(n)$ represent the mean of $y'(n)$. It can be described in the model in terms of the other parameters as follows:

$$\mu(n)=\alpha(n)\beta(n)+(1-\alpha(n))\delta(n). \qquad [6]$$

The seasonal variations of these parameters are also represented by Fourier series, and the means, amplitudes, and phase angles are estimated by numerical maximization of the log likelihood function as described by Woolhiser et al. (1988). Significant harmonics are determined by the Akaike information criterion (AIC) (Akaike 1974).

Expected Annual Precipitation

In this model the precipitation occurrence, X(n), is assumed to be independent of the distribution of amounts. (This seems to be a good assumption; see Stern and Coe 1984, Woolhiser and Roldan 1982.) Under this assumption the expected total precipitation for m days, E{S(m)}, is written as

$$E\{S(m)\} = \sum_{n=1}^{m} E\{X(n)Y(n)\} = \sum_{n=1}^{m} E\{Y(n)\}E\{X(n)\}, \qquad [7]$$

where

$Y(n)$ = the precipitation depth on day n,

$E\{X(n)\}=P\{X(n)=1\}=P\{X(n-1)=0\}p_{01}(n)+P\{X(n-1)=1\}p_{11}(n)$, and

$E\{Y(n)\}=\alpha(n)\beta(n)+[1-\alpha(n)]\delta(n)+T.$

Thus, annual precipitation is calculated using the following equation:

$$E\{S(m)\} = \sum_{n=1}^{365} [P\{X(n-1)=0\}p_{01}(n)+P\{X(n-1)=1\}p_{11}(n)]$$

$$[\alpha(n)\beta(n)+\{1-\alpha(n)\}\delta(n)+T]. \qquad [8]$$

Precipitation that falls on the extra day in a leap year is not accounted for in this model.

Distribution of Total Precipitation in m Days

In this model the total precipitation in m days is written as

$$S(m) = \sum_{n=1}^{m} X(n)Y(n). \qquad [9]$$

Thus, the distribution function of S(m) is written as

$$F_m(s)=P\{S(m)\leq s\}=P\{S(m)=0\}+\sum_{n=1}^{m} P\{S(m)\leq s \mid N(m)=n\}$$
$$P\{N(m)=n\}, \qquad [10]$$

where N(m) is the number of wet days in the m–day period.

An analytical expression for this distribution was derived by Todorovic and Woolhiser (1975) using results from Gabriel (1959) and Gabriel and Neuman (1962) for the Markov chain counting process and the exponential distribution for the daily precipitation. This expression is as follows:

$$F_m(s)=(1-q_0-Rd)(1-q_0)^{m-1}+\sum_{k=1}^{m} [R\psi_1(m,k)+(1-R)\psi_0(m,k)]$$

$$\frac{\lambda^k}{k}\int_0^{s-kT} u^{k-1}e^{-\lambda u}du, \qquad [11]$$

where

$\lambda=1/\mu(n)$,

where n is the day at or adjacent to the midpoint of period m;

$q_0=p_{01}=1-p_{00}$;

$q_1=p_{11}=1-p_{10}$;

$d=q_1-q_0=p_{00}-p_{10}$;

$R=p\{X_0=1\}$,

where X_0 refers to the occurrence process on the day before the m-day period;

$\psi_1(m,k)=P\{N(m)=k \mid X_0=1\}$

$$=q_1^k(1-q_0)^{m-k}+\sum_{c=1}^{C_1}\binom{k}{a}\binom{m-k-1}{b-1}\left(\frac{1-q_1}{1-q_0}\right)^b\left(\frac{q_0}{q_1}\right)^a,$$

where

$$C_1=\begin{cases} m+1/2-|2k-m+1/2|, & \text{if } k<m \\ 0, & \text{if } k=m, \end{cases}$$

$a=\inf\{\nu;\ \nu\geq 1/2(c-1)\}$, and

$b=\inf\{\nu;\ \nu\geq 1/2\ c\}$; and

$\psi_0(m,k)=P\{N(m)=k \mid X_0=0\}$

$$=q_1(1-q_0)^{m-k}+\sum_{c=1}^{C_0}\binom{k-1}{b-1}\binom{m-k}{a}\left(\frac{1-q_1}{1-q_0}\right)^a\left(\frac{q_0}{q^1}\right)^b,$$

where

$$C_0=\begin{cases} m+1/2-|2k-m+1/2|, & \text{if } k>0 \\ 0, & \text{if } k=0. \end{cases}$$

Estimation of Temperature and Radiation

This model uses a multivariate process to estimate maximum temperature (t_{max}), minimum temperature (t_{min}), and solar radiation (r). The process was taken from Richardson (1981) and is based on the weakly stationary generating process used by Matalas (1967) for generating streamflow at multiple sites. The basic equation used by Richardson is:

$$t_j(n) = \chi_j(n) s_j(n) + \mu_j(n), \qquad [12]$$

where $t_1(n)$ is the daily value of t_{max} on day n, $t_2(n)$ is t_{min} on day n, $t_3(n)$ is the value of r on day n, $s_j(n)$ is the standard deviation, and $\mu_j(n)$ is the mean of t_j for day n. The values of $\mu_j(n)$ and $s_j(n)$ are conditioned on whether the day was dry or wet as determined by the Markov chain occurrence model. $\chi_j(n)$ is a vector of residuals obtained from the following equation:

$$\chi_j(n) = A\chi_j(n-1) + B\epsilon_j(n), \qquad [13]$$

where $\chi_j(n)$ is a vector having elements that are the standardized residuals of t_{max}, t_{min}, and r; A and B are 3 by 3 matrices with elements defined to maintain the appropriate serial and cross-correlation coefficients; and ϵ_j is a vector of independent, normally distributed random variables having a mean of 0 and a standard deviation of 1. The A and B matrices are given by

$$A = M_1 M_0^{-1} \text{ and} \qquad [14]$$

$$B B^T = M_0 - M_1 M_0^{-1} M_1^T, \qquad [15]$$

where the superscripts -1 and T denote the inverse and transpose matrices, respectively. M_0 and M_1 are defined as

$$M_0 = \begin{bmatrix} 1 & \rho_0(1,2) & \rho_0(1,3) \\ \rho_0(1,2) & 1 & \rho_0(2,3) \\ \rho_0(1,3) & \rho_0(2,3) & 1 \end{bmatrix}$$

$$M_1 = \begin{bmatrix} \rho_1(1) & \rho_1(1,2) & \rho_1(1,3) \\ \rho_1(2,1) & \rho_1(2) & \rho_1(2,3) \\ \rho_1(3,1) & \rho_1(3,2) & \rho_1(3) \end{bmatrix}$$

where $\rho_0(j,k)$ is the correlation coefficient between variables j and k on the same day, $\rho_1(j,k)$ is the correlation coefficient between variables j and k with variable k lagged 1 day, and $\rho_1(j)$ is the lag 1 serial correlation coefficient for variable j.

Richardson (1982) found that the correlation coefficients in matrices M_0 and M_1 showed little spatial variability for 31 locations in the United States.

The average correlation coefficients given by Richardson (1982) and Richardson and Wright (1984) are

$$M_0 = \begin{bmatrix} 1.000 & 0.633 & 0.186 \\ 0.633 & 1.000 & -0.193 \\ 0.186 & -0.193 & 1.000 \end{bmatrix}$$

$$M_1 = \begin{bmatrix} 0.621 & 0.445 & -0.087 \\ 0.563 & 0.674 & -0.100 \\ 0.015 & -0.091 & 0.251 \end{bmatrix}$$

The A and B matrices can be computed for these values from equations 14 and 15 and are as follows:

$$A = \begin{bmatrix} 0.567 & 0.086 & -0.002 \\ 0.253 & 0.504 & -0.050 \\ -0.006 & -0.039 & 0.244 \end{bmatrix}$$

$$B = \begin{bmatrix} 0.782 & 0 & 0 \\ 0.328 & 0.637 & 0 \\ 0.238 & -0.341 & 0.873 \end{bmatrix}$$

Equation 12 can be written in the form

$$t_j(n)=\mu_j(n)[\chi_j(n)c_j(n)+1], \qquad [16]$$

where $c_j(n)$ is the coefficient of variation. The seasonal changes in the means and coefficients of variation are represented by the following equation:

$$u_j(n)=\bar{\mu}_j+c_j\cos[0.0172(n-D_j)],\ n=1,\ 2,\ ...365, \qquad [17]$$

where $u_j(n)$ is the mean or coefficient of variation on day n, $\bar{\mu}_j$ is the annual mean, c_j is the amplitude of the first harmonic, and D_j is the phase angle in days. The value of these variables was originally determined from 20 years of data for 31 U.S. locations and is presented in maps and tables in Richardson and Wright (1984).

We found two problems with the weather generation scheme used in WGEN and corrected these problems in USCLIMAT.BAS. One problem was associated with recorded mean minimum temperatures less than 0 °F—a common occurrence at climate stations east of the Rocky Mountains along the Canadian border or on the northern Great Plains. Furthermore, the standard deviations of the generated temperature records were low during the summer and midwinter and very high during early spring and fall. These problems were corrected by adding 100 °F to all daily maximum and minimum values; thus the maps of coefficient of variation in USCLIMAT.BAS reflect this temperature data adjustment.

The other problem had to do with solar radiation data. Experience with WGEN showed that daily generated solar radiation data did not represent actual conditions in northern latitudes. This problem was corrected by separating the amplitude of wet and dry day solar radiation data (see appendix maps A11 and A13). When recorded values of daily solar radiation were >80 percent of the maximum potential incoming solar radiation, Richardson and Wright (1984) adjusted the value to fall on the boundary line when computing the daily mean and standard deviation for each climate station. When WGEN generated solar radiation data, we found that the upper limit of 80 percent of the maximum potential incoming solar radiation was too restrictive for stations in the southwest and that the lower limit of 20 percent was too restrictive on cloudy days for stations in the northeast, so we used limits of 90 percent and 10 percent instead. These limits are used for generating daily solar radiation data because otherwise the climate generator would occasionally generate unrealistic values.

In USCLIMAT.BAS, 20 years of data from at least 40 U.S. locations were used to develop the maps in the appendix for temperature and solar radiation data generation.

Daily Weather Simulation

Markov chain process
If the preceding day is dry, a uniform random number represented by u ($0 \leq u \leq 1$) is generated. If $u < p_{00}(n)$, day n is dry; if $u \geq p_{00}(n)$, day n is wet. If the preceding day is wet, a uniform random number represented by u is generated. If $u < p_{10}(n)$, day n is dry; if $u \geq p_{10}(n)$, day n is wet.

Mixed exponential distribution
If day n is wet, a new, uniform random number is generated. If $u < \alpha(n)$, the depth is generated from an exponential distribution with mean $\beta(n)$ using the transformation

$$y = -\beta(n) \log u + 0.008. \qquad [18]$$

If $u \geq \alpha(n)$, the depth is generated from an exponential distribution as follows:

$$y = -\delta(n) \log u + 0.008, \qquad [19]$$

where $\delta(n)$ is the mean. The depth 0.008 inch is added because the raw data are transformed by subtracting the threshold depth 0.008, so the mixed exponential has a lower bound of nearly zero.

T_{max}, T_{min}, and radiation
The residuals in equation 13 are generated using the following transformations from Naylor et al. (1966):

$$r_1 = [-2 \log u_1 \cos(2\pi u_2)]^{1/2} \qquad [20]$$
$$r_2 = [-2 \log u_1 \sin(2\pi u_2)]^{1/2},$$

where r_1 and r_2 are independent normal (0,1) random variables and u_1 and u_2 are independent, uniformly distributed random variables. Because three normally distributed residuals are required for each day, six random variables are generated at one time and are used for 2 days. In the current version of the program, the random number generator in BASIC is used to generate u_1 and u_2.

Provisions have been included in USCLIMAT.BAS for either simulating 365-day years and for simulating 366-day years (for leap years). Simulation starts on March 1. The user selects which of the first 4 years is the leap year and the program then accounts for the fact that every fourth successive year is a leap year. Weather data for February 29 are simulated by using parameter values that were used to generate data for February 28 with new random numbers. In leap years wet and dry day sequences for March 1 are based on data from February 29.

Distribution Function for m-Day Precipitation

The program provides an analytic solution for the distribution function $F_m(s)$, equation 11, using solutions for $\psi_1(m,k)$ and $\psi_0(m,k)$ for $1 \leq m < 30$. The parameters in equation 11 are all treated as constants within the m-day period and are estimated for the midpoint of the period. The parameter λ (in equation 11) for the exponential distribution is estimated by the model from the mean of the mixed exponential, that is,

$$\lambda = \alpha\beta + (1-\alpha)\delta. \qquad [21]$$

The integral in equation 11 is

$$\int_0^{s-kT} u^{k-1} e^{-\lambda u} \, du$$

and is solved recursively using the following relationship found in standard tables of integrals:

$$\int x^m \exp(ax)dx = (x^m \exp(ax)/a) - (m/a)\int x^{m-1}\exp(ax)dx. \qquad [22]$$

The Microcomputer Program

The flowchart for the program USCLIMAT.BAS is shown in figure 1.

Input for Maps

Latitude and longitude values are the only data required to initiate the map routines in USCLIMAT.BAS. After the latitude and longitude data have been entered, the program will draw the state boundaries that are within an area bounded by 2° latitude and 3° longitude on either side of the central point chosen. If any of the 360 climatic stations are located within the area, they are plotted on the screen. A small rectangular cursor, located in the middle of the grid, can be moved by the arrow keys to the desired location on the map, and circles with radii of 30 and 100 miles are projected on the screen as an aid to the user.

Parameter Interpolation

As in CLIMATE.BAS (Woolhiser et al. 1988:12), the two options for interpolating or selecting parameters in USCLIMAT.BAS are (1) to use the arithmetic average of parameters from stations within a radius of 100 miles and (2) to use the parameters of the nearest neighbor.

Precipitation is strongly affected by orographic factors, so parameter averaging should not be used if adjacent stations differ widely in elevation. There is some evidence (Osborn et al. 1987, Hanson and Woolhiser 1990) that the parameters in the Markov chain/mixed exponential model can be adjusted for elevation, but more research is required before these adjustments can be incorporated into this microcomputer program.

In USCLIMAT.BAS, if the nearest station is closer than 30 miles, as identified by the inner circle on the screen, the user is asked if the parameters for the nearest station are to be used. If the user answers "yes," the program uses those parameters to generate data. If the user answers "no," the parameters for the stations within a 100-mile radius are averaged and used The user has the option to omit parameters of any of these stations from being included in the average or to obtain any or all of the parameters from appendix figures A1–A17.

In the example that follows, McCall, ID, is within the 100-mile radius of the location desired. But the parameters from McCall are omitted because the McCall station is at a much higher elevation than the other stations and has more precipitation and cooler temperatures. On the other hand, if estimated parameters for a station between Boise and McCall were needed, all stations with an elevation lower than that of Boise might be eliminated. In the averaging procedure, all amplitudes, including amplitudes of zero, are averaged, but phase angles for nonsignificant harmonics are not included in the average.

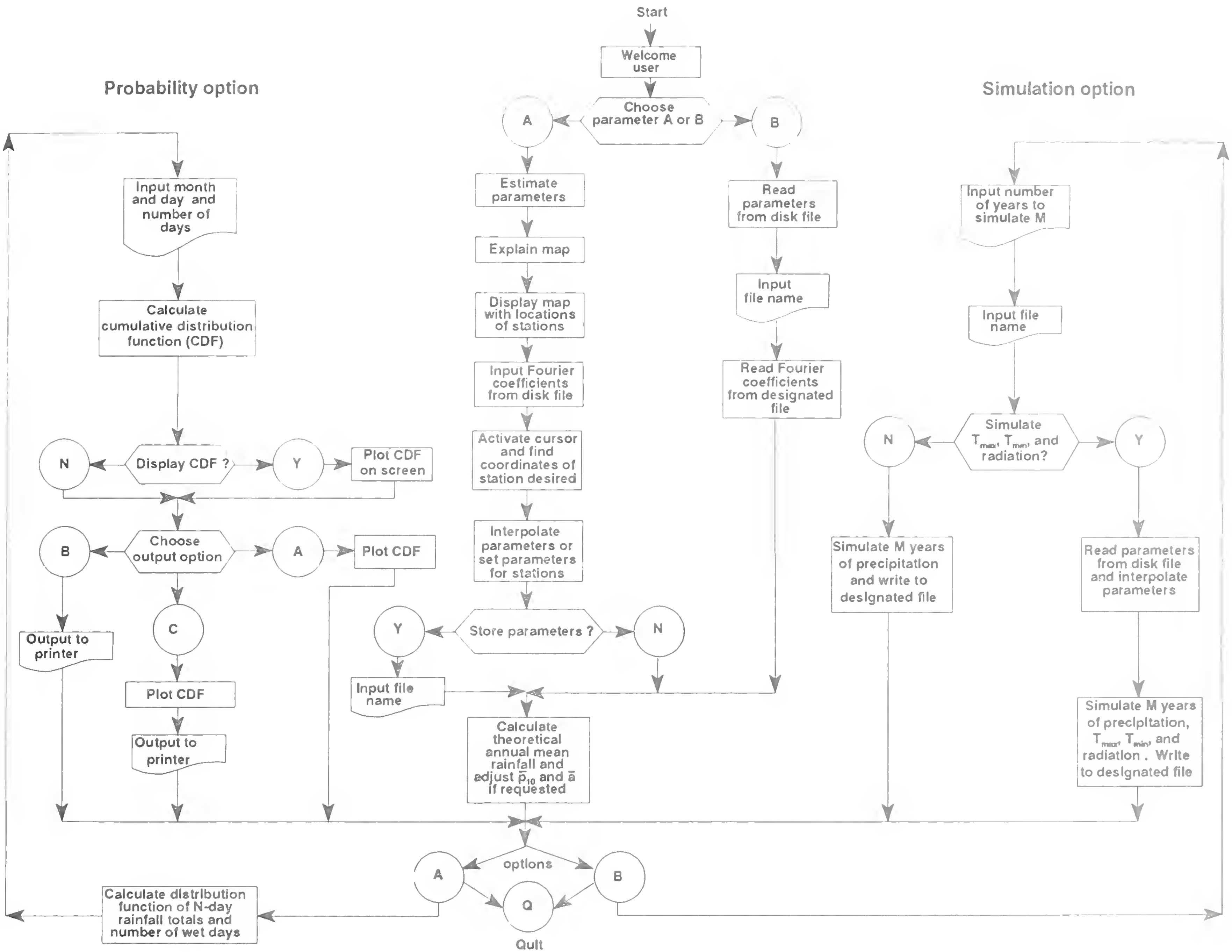


Figure 1. Flowchart for USCLIMAT.BAS program

Parameter Identification

The parameter matrix Z(I,J,K), read in statement 760 from the sequential file "SITES," consists of the means, amplitudes, and phase angles of six harmonics for the Fourier series representation of p_{00}, p_{10}, β, and μ in equations 2, 3, 5, and 6. The index I refers to the station number. As shown in the following, J refers to the parameter and K refers to the mean, amplitude, or phase angle, depending on the value of K:

J	Parameter
1	p_{00}
2	p_{10}
3	β
4	μ

K	Fourier parameter
1	Annual mean
2	Amplitude of first harmonic
3	Phase angle of first harmonic
4	Amplitude of second harmonic
5	Phase angle of second harmonic
6	Amplitude of third harmonic
7	Phase angle of third harmonic
8	Amplitude of fourth harmonic
9	Phase angle of fourth harmonic
10	Amplitude of fifth harmonic
11	Phase angle of fifth harmonic
12	Amplitude of sixth harmonic
13	Phase angle of sixth harmonic

These parameters were identified from 20 to 40 years of daily precipitation data using the program AGUA46, which provides approximate maximum likelihood estimates of the means, amplitudes, and phase angles. Procedures were developed by Woolhiser and Pegram (1979), Roldan and Woolhiser (1982), and Woolhiser and Roldan (1986). A discussion of AGUA46 and a copy of the program can be found in the publication by Woolhiser et al. (1988).

Parameter Estimation for Temperature and Radiation

The parameters W(1) through W(17) are required to describe mean values of t_{max}, t_{min}, and r. These parameters are defined as follows:

Parameter	Definition (temperatures in °F, radiation in Langleys)
W(1)	Annual mean of t_{max} for dry days
W(2)	Amplitude of t_{max} for wet or dry days
W(3)	Annual mean of the coefficient of variation of t_{max} for wet or dry days
W(4)	Amplitude of the coefficient of variation of t_{max} for wet or dry days
W(5)	Annual mean of t_{max} for wet days
W(6)	Annual mean of t_{min} for wet or dry days
W(7)	Amplitude of t_{min} for wet or dry days
W(8)	Annual mean of the coefficient of variation of t_{min} for wet or dry days
W(9)	Amplitude of the coefficient of variation of t_{min} for wet or dry days
W(10)	Annual mean of r for dry days
W(11)	Amplitude of r for dry days
W(12)	Annual mean of r for wet days
W(13)	Amplitude of r for wet days

W(14)	Annual mean of the coefficient of variation of r for dry days
W(15)	Amplitude of the coefficient of variation of r for dry days
W(16)	Annual mean of the coefficient of variation of r for wet days
W(17)	Amplitude of the coefficient of variation of r for wet days

Parameters W(1)–W(13) are read for each station from the file named "TEMP" and are estimated by linear interpolation from appendix figures A1–A13. The original version of WGEN required reading only 12 parameters for each station, but, as discussed earlier, the number of parameters was increased in USCLIMAT.BAS to more accurately represent the temperature and solar radiation in some areas of the United States. W(14)–W(17) are fixed average values representing a large part of the contiguous United States.

Temperature and Radiation Corrections for Specific Locations

If information is available to justify the action, the user has the option of adjusting all 17 parameters to be more representative of specific locations, such as mountain sites. For example, because there are relatively large differences between the average solar radiation parameters used in USCLIMAT.BAS and those shown in appendix figures A14–A17 for southwest Arizona and southern Florida, adjustments can be made through linear interpolations from the figures for these areas.

Parameter Adjustment to Correct Mean Annual Precipitation

When the parameters for a station have been estimated by averaging those of surrounding stations, the theoretical annual average precipitation calculated by equation 8 may be slightly different from the estimated annual precipitation obtained by interpolation on an isohyetal map. An option within the program allows the parameters $\bar{\alpha}$ and $\bar{p}_{10}$ to be adjusted by a Newton-Raphson iterative procedure so that the theoretical mean is within $\pm$ 0.1 percent of the known average annual precipitation. The corrections are partitioned equally between $\bar{\alpha}$ and $\bar{p}_{10}$ according to the following equations:

$$0.5F + \frac{\partial F}{\partial \bar{p}_{10}} \Delta \bar{p}_{10} = 0 \quad [23]$$

$$0.5F + \frac{\partial F}{\partial \bar{\alpha}} \Delta \bar{\alpha} = 0, \quad [24]$$

where F is the difference between the theoretical and known average precipitation, and $\Delta \bar{p}_{10}$ and $\Delta\bar{\alpha}$ are corrections. The derivations are approximated by making the parameters p_{00}, p_{10}, α, β, and δ in equation 8 constants and taking the partial derivatives as follows:

$$\frac{\partial F}{\partial \bar{p}_{10}} = \frac{1-\bar{p}_{00}}{(1+\bar{p}_{10}-\bar{p}_{00})^2} [\bar{\alpha}\ \bar{\beta}+(1-\bar{\alpha})\ \delta\ ]\ 365 \quad [25]$$

$$\frac{\partial F}{\partial \bar{\alpha}} = -\left[\frac{1-\bar{p}_{00}}{1+\bar{p}_{10}-\bar{p}_{00}}\right] [\,\bar{\beta}-\bar{\delta}\,]\,365, \qquad [26]$$

where the bar above the parameter indicates the constant value in the Fourier series expression. $\bar{\alpha}$ and $\bar{p}_{10}$ were chosen for adjustment because they typically have greater variances than the other parameters.

Running USCLIMAT.BAS (an Example)

Running USCLIMAT.BAS requires the following: (1) an IBM or IBM-compatible personal computer, (2) a color graphics board or a color graphics board emulator, and (3) the program diskette that comes with this publication and contains the necessary programs and files. Once these items are obtained, set the default drive on the personal computer to the drive where you plan to load the program (usually A or B). Load the BASIC interpreter (called BASICA). Insert the program diskette into the default drive, load USCLIMAT.BAS, and type "RUN" to execute the program.

During each phase of the program, the screen flashes documentation and directions to the user. The first screen (fig. 2) introduces the user to the program. The second screen (fig. 3) offers two ways to obtain weather parameters: (A) from user input and (B) from a disk file of parameters stored in an earlier run. First-time users should type "A" and then press the ENTER key. The third screen (fig. 4) shows the user how to arrive at the desired location.

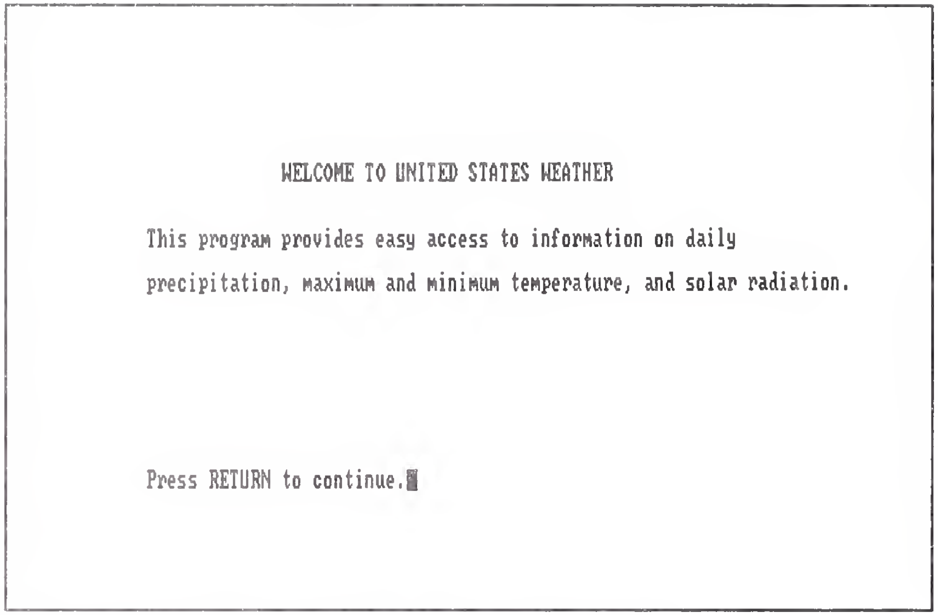


Figure 2. Welcome screen for microcomputer program

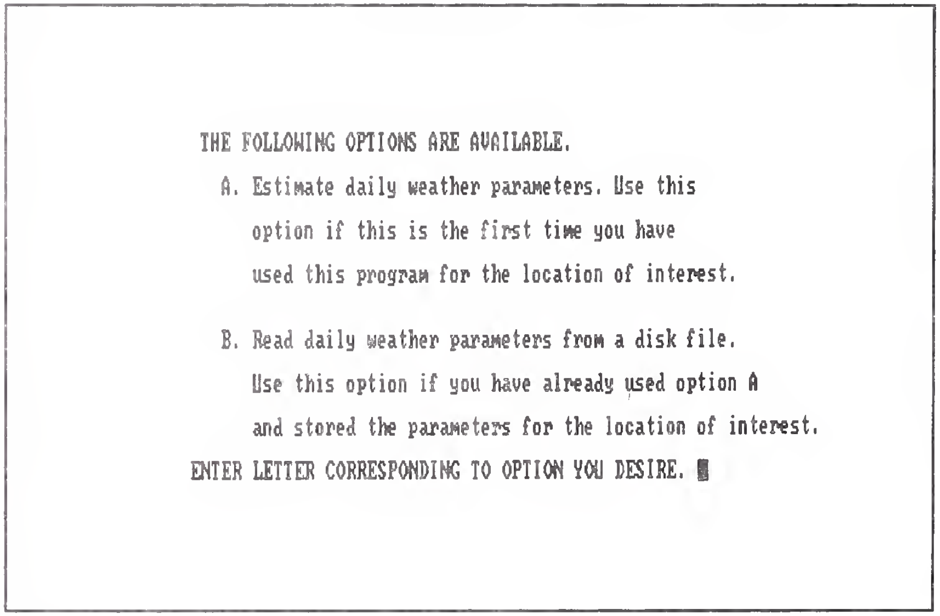


Figure 3. Option screen

```
THE NEXT SCREEN WILL SHOW A REGIONAL MAP WITH A USER-DEFINED CENTRAL SITE
AND LOCATIONS OF WEATHER STATIONS IN THE VICINITY.

ENTER APPROXIMATE LATITUDE, LONGITUDE FOR CENTRAL SITE 44,116

USE THE ARROWS ON YOUR KEYBOARD TO PLACE THE CURSOR AT THE POSITION
WHERE INFORMATION IS DESIRED. CIRCLES OF 30 AND 100 MILES RADII WILL BE DRAWN.
THE SCALE IS 69 MILES BETWEEN LATITUDE LINES NORTH AND SOUTH AND 53 MILES
BETWEEN LONGITUDE LINES EAST AND WEST. PRESS ANY KEY TO CONTINUE.█
```

Figure 4. Information screen

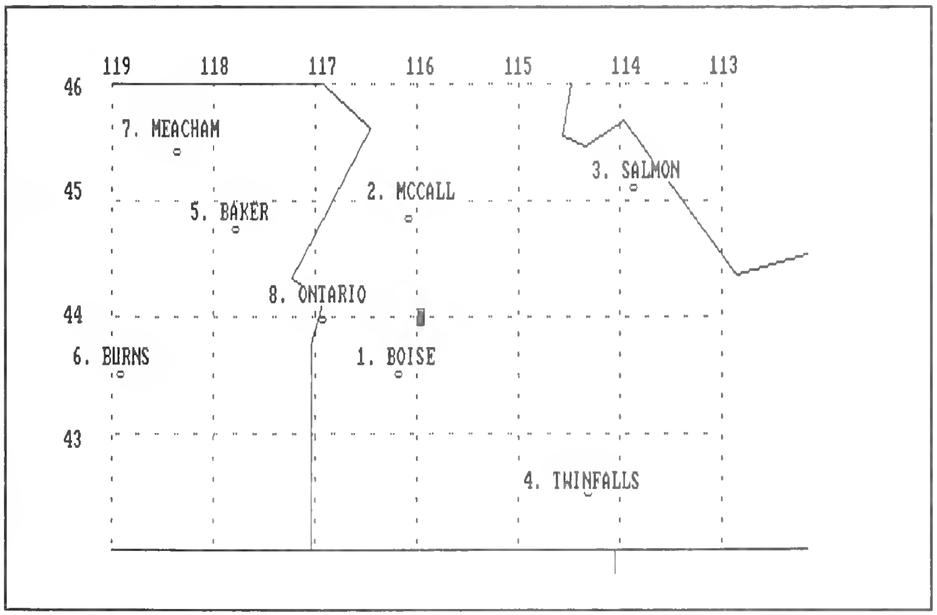
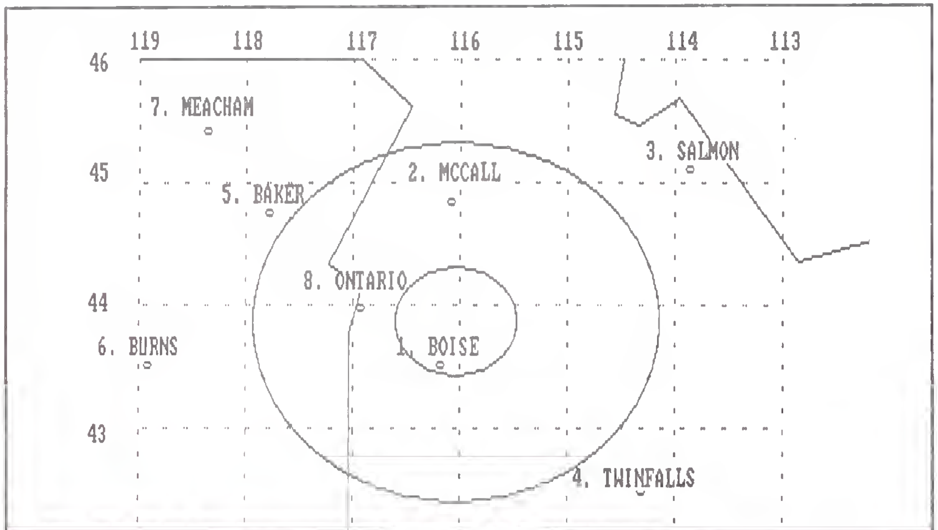


Figure 5. Map showing weather stations in the region surrounding the point having a latitude of 44° and longitude of 116°

When the model is run, the computer first asks for an approximate latitude and longitude. If decimals are used, they are rounded by the program to the nearest integer. In the example that follows we typed "44, 116" for the latitude and longitude and then pressed the ENTER key (fig. 4, line 3). Next, the screen described the map routine and how to move the cursor to the desired location. The program constructed a grid (fig. 5) of the area within 2 degrees latitude and 3 degrees longitude of the central site. State boundary lines were drawn and a search made in the file "SITES" to determine which of 360 weather stations are located within the grid. Depending on the speed of the computer's processing chip, this process can take up to 4 minutes to complete.

After plotting and labeling all suitable stations, the program placed a small rectangular cursor in the center of the grid (fig. 5). Using the arrow keys, we moved the cursor one space down and one space to the left and pressed the ENTER key. Two concentric circles with radii of 30 and 100 miles appeared (fig. 6). The Boise station appeared within the 30-mile circle. The program asked whether the parameters should be taken from just the Boise station. We typed "Y" for "yes" and then pressed the ENTER key. The program then asked whether the station's parameters should be stored for later use. We typed "N" for "no" and then pressed the ENTER key. If we had answered "yes", it would have asked for a file name and then would have stored the parameters on the designated disk. Once the user has created such a file, the file can be called in future runs by answering "B" to the inquiry in figure 3.

The program gives the user some options regarding which station's parameters will be used. We could have chosen not to limit the parameters to those of the closest station. The user also has the option to eliminate from consideration any of the stations in the 30-




```
DO YOU WISH TO USE PARAMETERS FOR STATION  1  ONLY (Y/N)?
```

Figure 6. Map of region with concentric circles around location where weather data are desired

```
AVERAGE PARAMETERS FOR STATION
P00
    0.8160E+00    0.1090E+00    -.1151E+01    0.1837E-01    0.1960E+01
    0.0000E+00    0.0000E+00    0.1278E-01    -.1521E+01    0.0000E+00
    0.0000E+00    0.0000E+00    0.0000E+00
P10
    0.5515E+00    0.1046E+00    -.7690E+00    0.3628E-01    0.7099E+00
    0.3922E-01    0.2051E+00    0.3593E-01    -.1333E+01    0.0000E+00
    0.0000E+00    0.0000E+00    0.0000E+00
BETA
    0.5483E-02    0.0000E+00    0.0000E+00    0.1914E-02    0.3368E+00
    0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
    0.0000E+00    0.0000E+00    0.0000E+00
MEAN
    0.1302E+00    0.1905E-01    -.9546E+00    0.0000E+00    0.0000E+00
    0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00    0.0000E+00
    0.0000E+00    0.9736E-02    -.1298E+01
ALPHA =  .16941

PRESS RETURN TO CONTINUE
```

Figure 7. Parameters for Boise, ID, station

and 100-mile radii. When choosing which stations to eliminate, the user must carefully examine the climate and geography of the stations and eliminate those that are incompatible. The following is an example: In figure 6 two stations, Ontario and McCall, fall within the 100-mile radius. But the parameters from McCall should probably be omitted because the McCall station is at a much higher elevation than the Ontario and Boise stations and has more precipitation and cooler temperatures. If the user selects both the Ontario and Boise stations, the parameters from these stations are averaged. In this example, however, we limited ourselves to the Boise station, so the program displayed just the Boise parameters (fig. 7) and then computed a mean annual precipitation for Boise with an accompanying mean number of wet days (line 2 of fig. 8). Line 3 in figure 8 asked us whether we knew the average annual precipitation. We typed "Y" for "yes" and then pressed the ENTER key. Next the program prompted us for the new precipitation figure; we typed "11.61" and then pressed the ENTER key. The program then readjusted the parameters $\bar{p}_{10}$ and $\bar{\alpha}$ until the calculated value for annual precipitation came within 0.1 percent of the corrected value.

```
CALCULATING
EXPECTED ANNUAL PRECIPITATION = 12.29547 INCHES. NO. WET DAYS= 91.35602

DO YOU KNOW THE AVERAGE ANNUAL PRECIPITATION (Y/N)  ? Y

ENTER AVERAGE ANNUAL PRECIPITATION IN INCHES XX.XX 11.61

CALCULATING
EXPECTED ANNUAL PRECIPITATION = 11.76655 INCHES. NO. WET DAYS= 89.31726

CALCULATING
EXPECTED ANNUAL PRECIPITATION = 11.64359 INCHES. NO. WET DAYS= 88.83268

CALCULATING
EXPECTED ANNUAL PRECIPITATION = 11.61709 INCHES. NO. WET DAYS= 88.72775

ALPHA AND P10 HAVE BEEN ADJUSTED TO MAINTAIN ANNUAL PRECIP.

PRESS RETURN TO CONTINUE
```

Figure 8. Iterative procedure to adjust average annual precipitationtion by modifying $\bar{\alpha}$ and $\bar{p}_{10}$

```
THE FOLLOWING OPTIONS ARE AVAILABLE
  A. Estimate the probability of X or less inches of precipitation
     over N days.
  B. Simulate M years of just precipitation data, or simulate
     precipitation, max and min temperature, and radiation data.
ENTER LETTER OF OPTION DESIRED OR Q TO QUIT
```

Figure 9. Option screen

```
THIS SUBROUTINE WILL CALCULATE THE PROBABILITY THAT THE PRECIPITATION
IN THE N-DAY PERIOD YOU SELECT WILL BE = OR < X INCHES.
ENTER THE MONTH AND DAY OF THE BEGINNING DAY, e.g. 3,25 FOR MAR. 25. 11,1
ENTER THE LENGTH, N, OF THE PERIOD IN DAYS. N SHOULD BE LESS THAN 30. 10
CALCULATING
WAS IT PRECIPITATING ON THE DAY BEFORE 11 - 1 (Y/N), DON'T KNOW (DK)? DK
DO YOU HAVE AN ESTIMATE OF THE PROBABILITY OF PRECIPITATION ON THE
DAY BEFORE (Y/N) ? Y
ENTER THE PROBABILITY OF PRECIPITATION ON THE DAY BEFORE IN THE FORM 0.XX. 0.40
```

Figure 10. Information screen for probability option

The second phase of the program offered two choices for applying the precipitation parameters (fig. 9): (A) Estimate precipitation probabilities over a period of time and (B) simulate climatic data for a number of years. We typed "A" and then pressed the ENTER key to select the probability routine.

The probability routine is quite flexible. The user enters a starting date, a time period of less than 30 days, and whether the day before the starting date was wet, dry, or unknown (fig. 10). In this example, we entered "11, 1" (fig. 10, line 3) for starting date, "10" for the number of days (line 4), and "DK" for not knowing whether it rained on October 31. The program asked whether we knew the probability of precipitation on the day before the chosen starting date (line 7). We answered "Y" and then pressed the ENTER key. Next, it prompted for the estimated probability (in decimal form) of rain on October 31 (line 9). We entered "0.40" and then pressed the ENTER key. The computer estimated the probabilities and displayed the results on two graphs. The first graph (fig. 11) shows the probability of the occurrence of a specified number of wet days and the

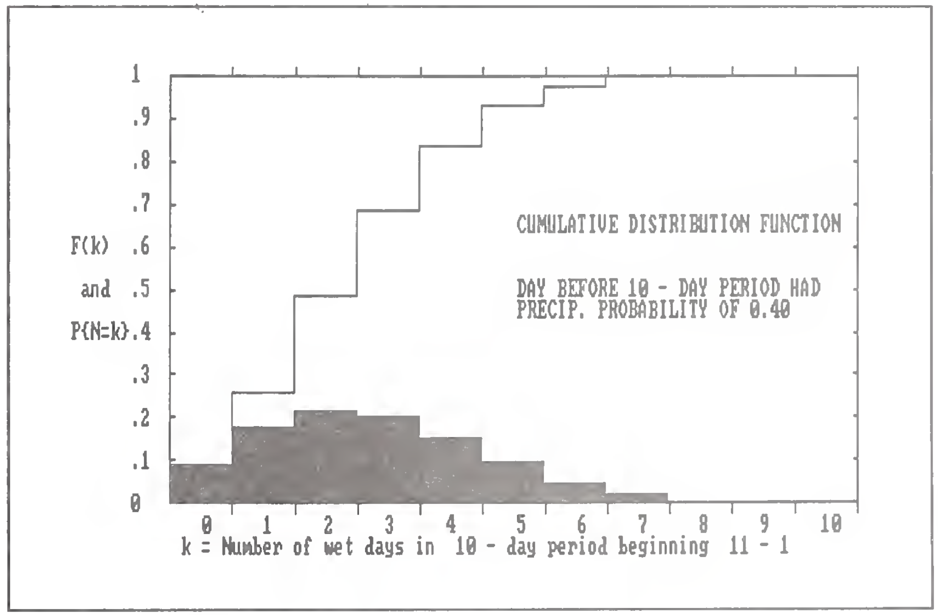


Figure 11. Cumulative distribution function and probability mass function of the number of wet days in a 10-day period

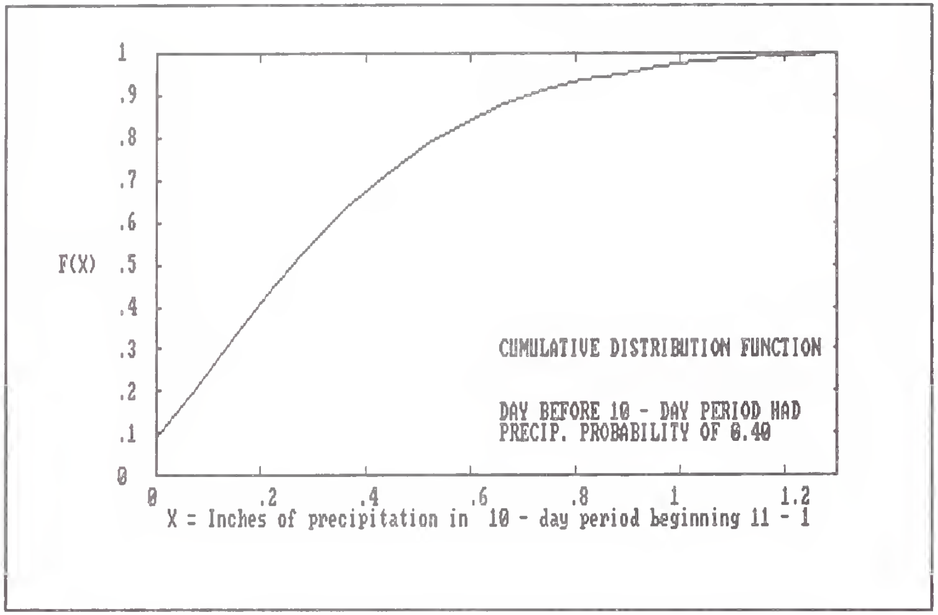


Figure 12. Cumulative distribution function of total precipitation in a 10-day period

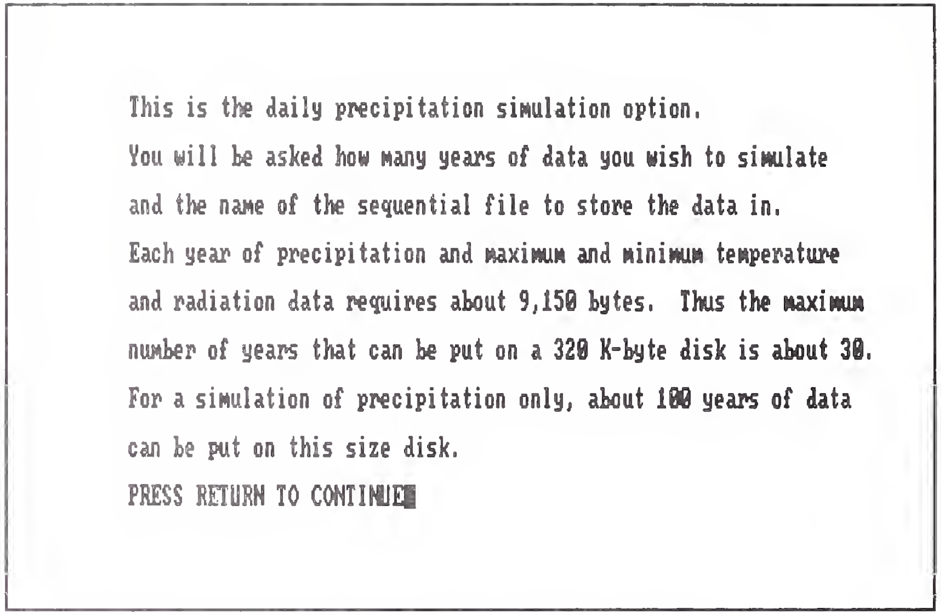

This is the daily precipitation simulation option.
You will be asked how many years of data you wish to simulate
and the name of the sequential file to store the data in.
Each year of precipitation and maximum and minimum temperature
and radiation data requires about 9,150 bytes. Thus the maximum
number of years that can be put on a 320 K-byte disk is about 30.
For a simulation of precipitation only, about 100 years of data
can be put on this size disk.
PRESS RETURN TO CONTINUE

Figure 13. Information screen for simulation option (part 1)

cumulative probability; the second graph (fig. 12) shows the cumulative probability of the occurrence of the specified total amount of precipitation in the period. After these graphs were produced, the program returned to the decision screen (fig. 9) to give us the option to determine more probabilities, create simulations, or exit the program. This time we typed "B" and then pressed the ENTER key to have the program simulate precipitation, temperature, and solar radiation.

The simulation routine allowed us to simulate precipitation only or to include simulations for temperature and solar radiation (figs. 13 and 14). The program asked us: (1) for the number of years for which the simulation will take place, (2) for a file name to store the data in, and (3) whether or not to simulate temperature and solar radiation (fig. 14). We typed "3" for question 1 (fig. 14, line 1), "Boise" for question 2 (line 3), and "Y" for question 3 (line 8). Since we answered "yes" to question 3, the program then asked us whether we wanted to use real precipitation data. We answered "no" (line 9). If we answered "yes" to this, the program would then

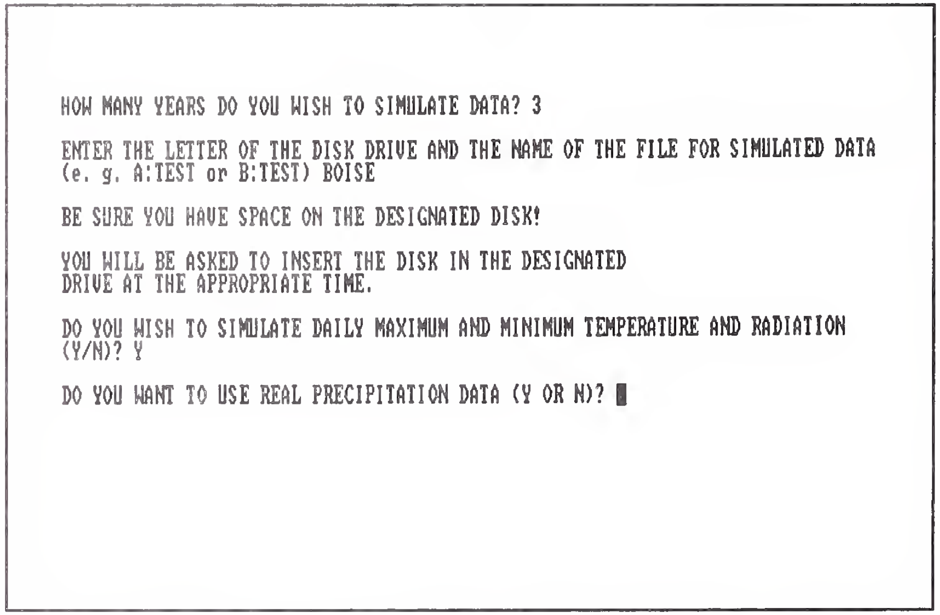

HOW MANY YEARS DO YOU WISH TO SIMULATE DATA? 3
ENTER THE LETTER OF THE DISK DRIVE AND THE NAME OF THE FILE FOR SIMULATED DATA
(e. g. A:TEST or B:TEST) BOISE
BE SURE YOU HAVE SPACE ON THE DESIGNATED DISK!
YOU WILL BE ASKED TO INSERT THE DISK IN THE DESIGNATED
DRIVE AT THE APPROPRIATE TIME.
DO YOU WISH TO SIMULATE DAILY MAXIMUM AND MINIMUM TEMPERATURE AND RADIATION
(Y/N)? Y
DO YOU WANT TO USE REAL PRECIPITATION DATA (Y OR N)?

Figure 14. Information screen for simulation option (part 2)

have asked us for the file name containing the real precipitation data and also would have cautioned us to make sure that the file contains sufficient data for the number of years for which the simulation would occur. (Each year's worth of data must start on March 1.) The user should use discretion on the number of years of simulation to avoid exceeding disk storage capacity.

Next, the program calculated daily maximum solar radiation potential based on Boise's latitude. Then it read 13 temperature and radiation parameters for Boise from the file "TEMP" and displayed them on the screen (fig. 15). In figure 15 we were given the option of changing these mean annual values (appendix figures A1–A13 show the parameter values used by the program). We typed "N" and then pressed the ENTER key. Next, the program displayed four parameters representing the coefficient of variation for solar radiation (fig. 16, lines 3–6) (appendix figs. A14–A17 show the parameter values used by the program). Since these parameter values are mean values that describe much of the continent, there is less need to adjust them. When we were given the chance to change these four parameters (fig. 16, line 7), we typed "N" and then pressed the ENTER key. Once the mean annual parameter values were established, the program calculated the daily parameter values for temperature and radiation. The precipitation parameters remained the same as those used in the previous probability run.

Before simulation, the program told us to put a diskette in the designated drive to receive the simulated data (fig. 16, line 11). Next, the program asked whether we wanted to account for leap years in the data (line 12). If we had answered "yes," the program would then have asked us "which of the first four years of the simulation will be a leap year?" We would then have typed a number from 1 to 4, establishing a sequence that would carry on for the entire simulation period. (All February 29 data are simulated using February 28

```
CALCULATING DAILY MAXIMUM SOLAR RADIATION

CURRENT TEMPERATURE AND SOLAR RADIATION PARAMETER VALUES:

 1. TXMD  =  63
 2. ATX   =  26
 3. CVTX  =  .058
 4. ACVTX = -.017
 5. TXMW  =  59
 6. TN    =  39
 7. ATN   =  17
 8. CVTN  =  .057
 9. ACVTN = -.017
10. RMD   =  430
11. ARD   =  276
12. RMW   =  283
13. ARW   =  211

DO YOU WANT TO CHANGE ANY OF THESE VALUES (Y OR N)?
```

Figure 15. Information screen for simulation option (part 3)

```
THE PROGRAM INITIALIZES THE FOLLOWING SOLAR RADIATION PARAMETERS AS MEAN VALUES
TAKEN FROM 31 WGEN WEATHER STATIONS:

14. CVRD  =  .244
15. ACVRD = -.084
16. CVRW  =  .488
17. ACVRW = -.135

DO YOU WANT TO CHANGE ANY OF THESE VALUES (Y OR N)? N

CALCULATING DAILY PARAMETER VALUES FOR TMAX, TMIN, AND R

SIMULATING  3  YEARS OF PRECIP., TMAX, TMIN, AND RADIATION.
EACH YEAR WILL TAKE FROM 1 TO 6 MINUTES. (TIME VARIES WITH THE TYPE OF PC)

INSERT DISK IN DESIGNATED DRIVE. PRESS RETURN TO CONTINUE.

DO YOU WANT LEAP YEARS (Y OR N)? N

Random number seed (-32768 to 32767)?
```

Figure 16. Information screen for simulation option (part 4)

parameters.) We answered "no" on line 12 of figure 16. Next the program asked for a random number seed to start the process. The user should type a number within the limits given. We typed "13579" (not shown on fig. 16) and then pressed the ENTER key. Processing data for each year takes from 1 to 6 minutes, depending on the disk drive used and the speed of the processing chip. This processing is speeded up considerably when simulating precipitation only.

Each simulation year begins on March 1, and the results are presented in the following order: precipitation (inches), maximum and minimum air temperature (both in degrees Fahrenheit), and solar radiation (Langleys). When the simulation is finished, the program returns to the decision screen (fig. 9). The user can then type "Q" and press the ENTER key to exit the program.

The program PRINT.BAS is provided to print the simulation results. When it is loaded and executed, the program can print daily weather results and monthly means for as many years as the user wants (fig. 17, line 7), providing the number doesn't exceed the file's capacity or the program's limit of 20 years. The program must be modified if the user wants to handle files covering periods greater than 20 years. The printout lines measure up to 132 characters wide. The user has the option of directing output to a printer, screen, or another disk file. In this example, the simulation results were directed to the screen. At the end of the program, the program calculates monthly and annual mean values over the time span.

```
Ok
RUN
ENTER FILE NAME (E.G. A:TEST OR B:TEST) BOISE
ENTER FILE TYPE: (1) PRECIP. ONLY OR (2) PRECIP., TEMP., AND SOLAR RAD. 2
DOES THIS FILE HAVE LEAP YEARS (Y OR N)? N

ENTER OUTPUT DIRECTION: (1) PRINTER, (2) SCREEN, OR (3) DISK FILE. 2
ENTER # OF YEARS TO PRINT 3█
```

Figure 17. Information screen for PRINT.BAS

Other Uses of USCLIMAT.BAS

The daily weather information available through USCLIMAT.BAS can be applied to many applications but is most useful as an input to other models that require daily precipitation, maximum and minimum temperature, and solar radiation data. Several water resource models such as SWRRB (Arnold et al. 1990), WEPP (Lane and Nearing 1989), and ERHYM–II (Wight 1987) require daily weather information that is not available for many locations in the United States but that can be simulated. Therefore, simulated weather data can be used to estimate hydrologic processes such as runoff and erosion rates. Sequences of daily weather data can also be used as input for many other applications from estimating plant growth and chemical transport to developing farm and ranch management plans and helping to improve knowledge of the climatology of the United States.

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Appendix. Parameters for Temperature and Radiation

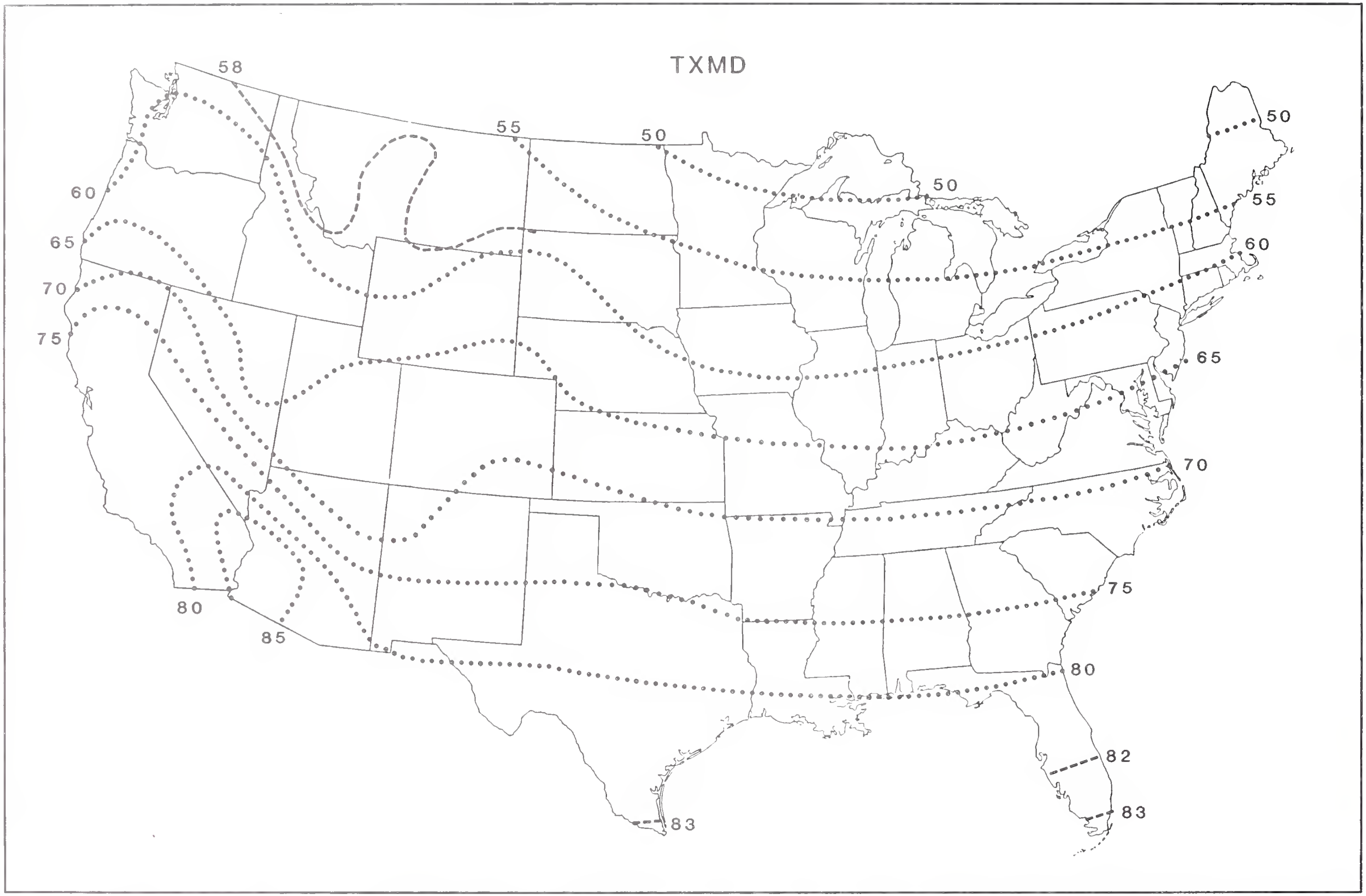

Figure A1. Distribution of the mean of t_{max} for dry days (TXMD), °F

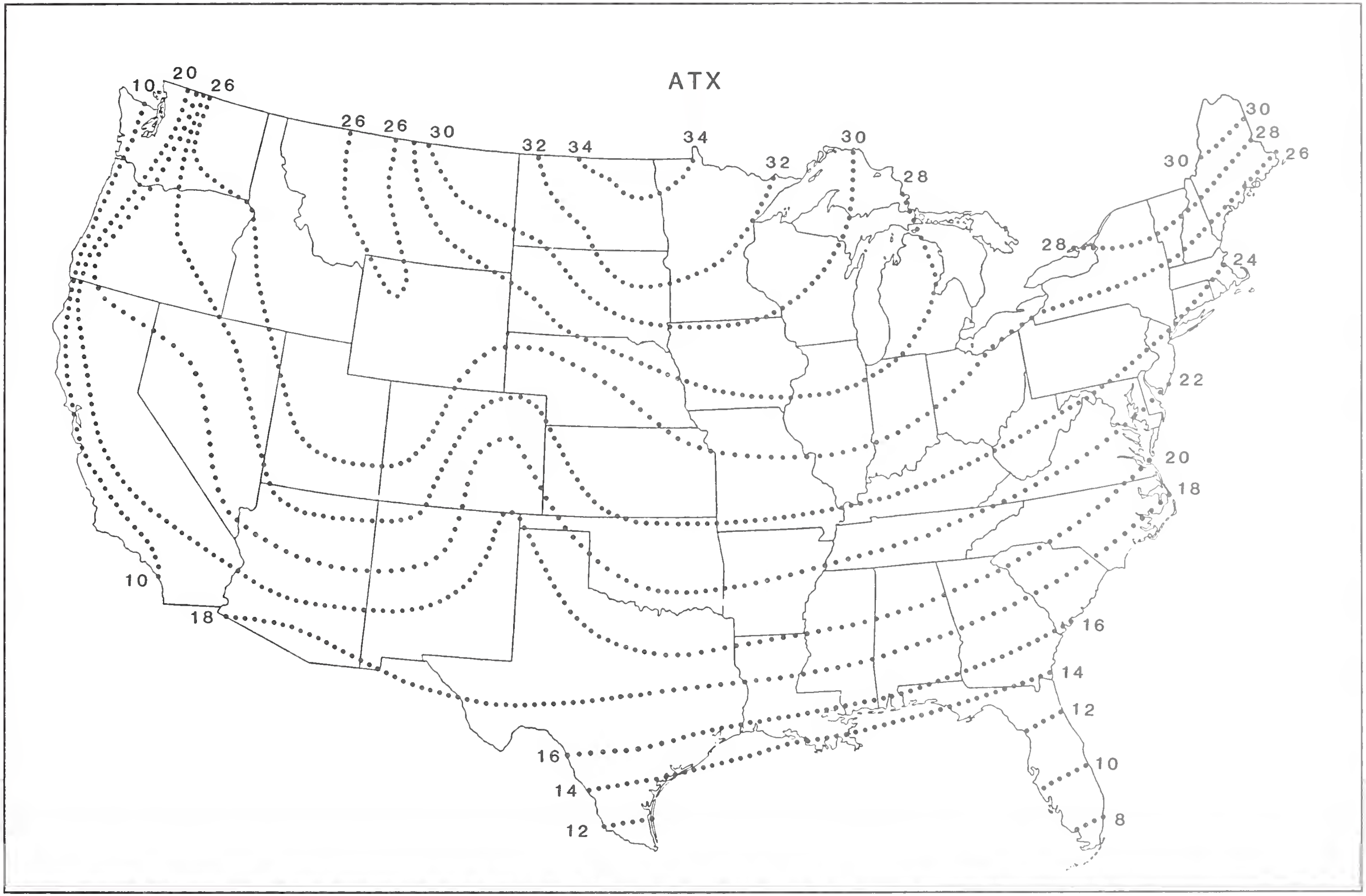

Figure A2. Distribution of the amplitude of t_{max} for wet or dry days (ATX), °F

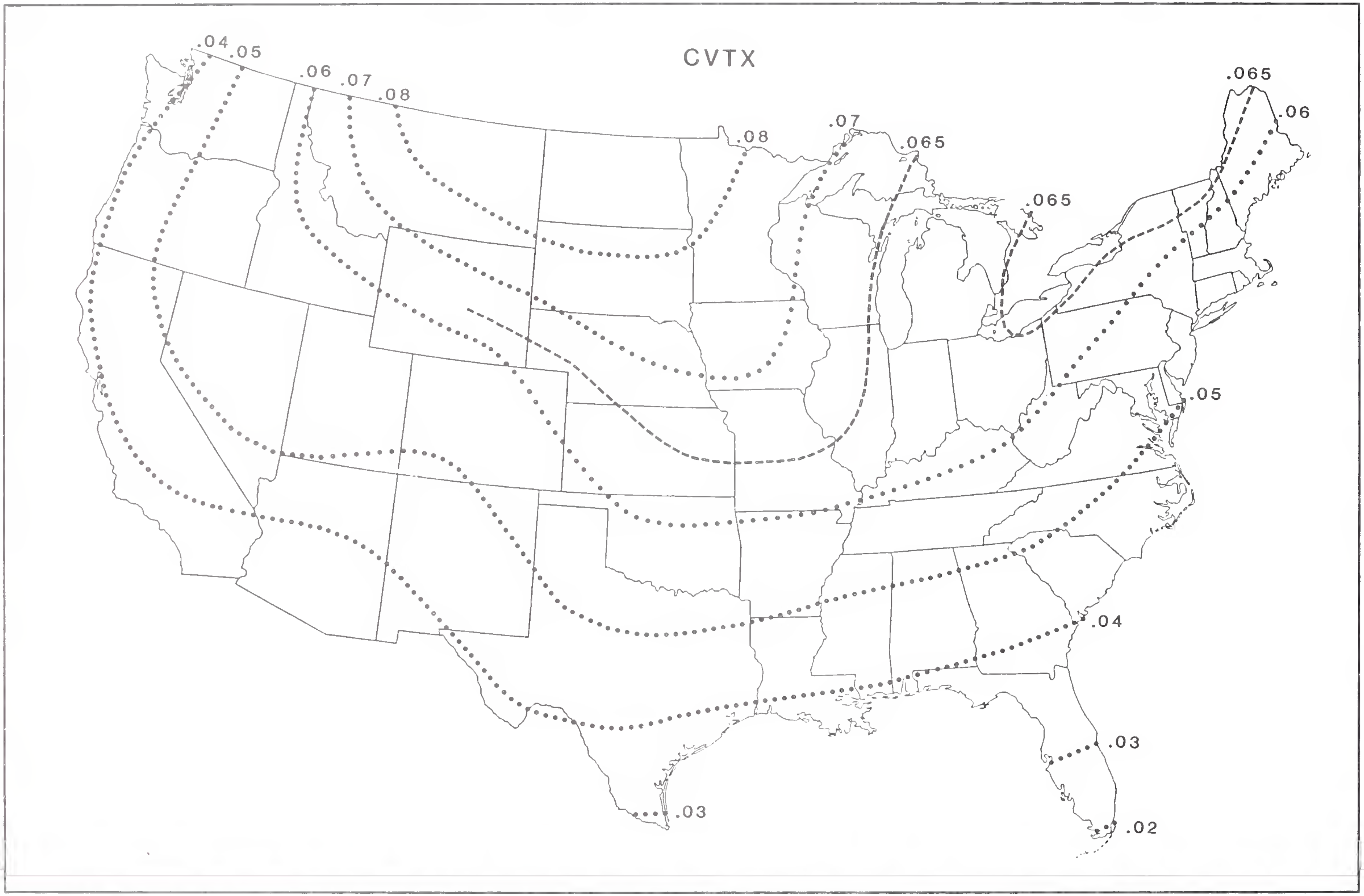

Figure A3. Distribution of the mean of the coefficient of variation of t_{max} for wet or dry days (CVTX)

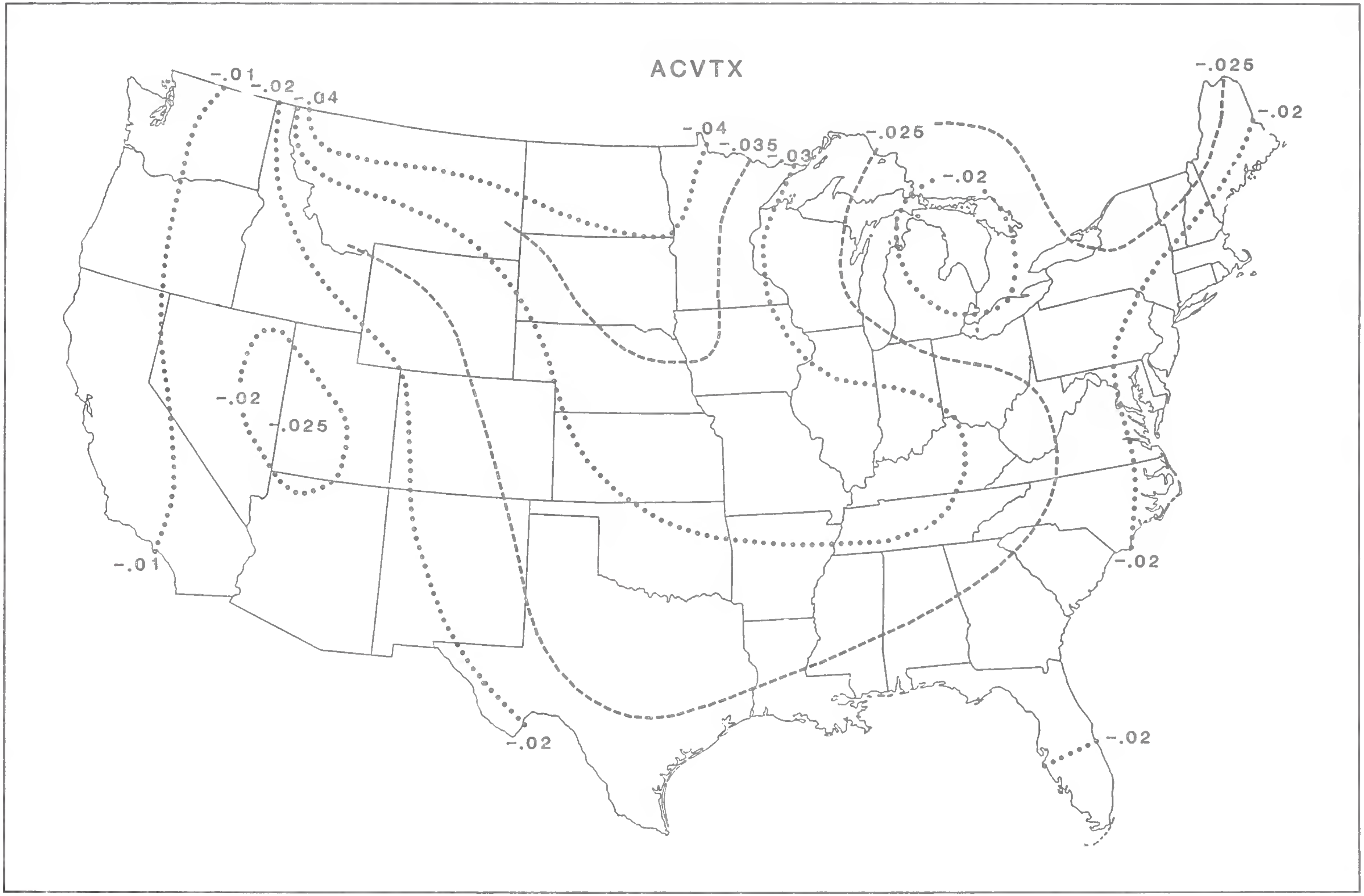

Figure A4. Distribution of the amplitude of the coefficient of variation of t_{max} for wet or dry days (ACVTX)

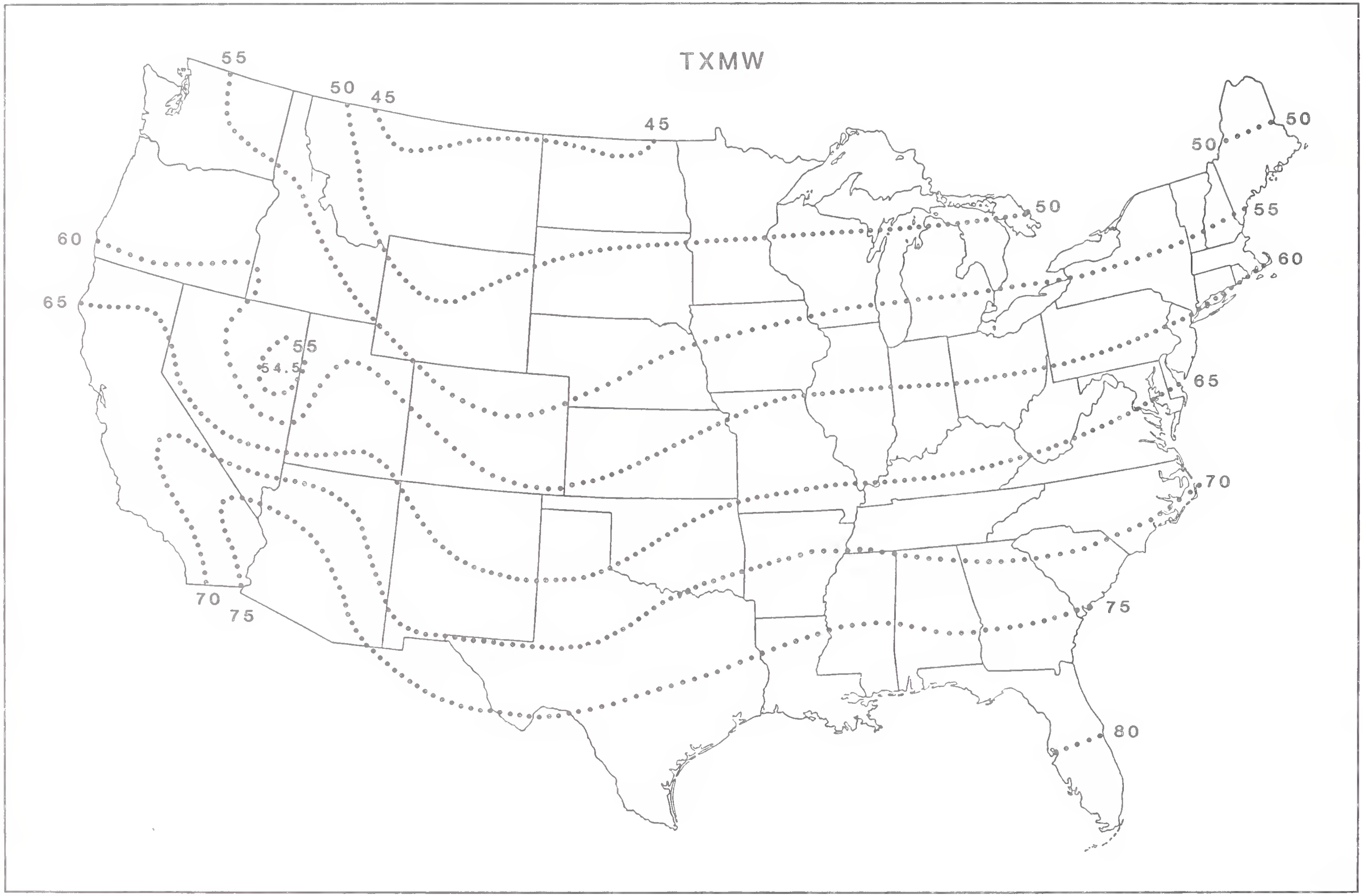

Figure A5. Distribution of the mean of t_{max} for wet days (TXMW), °F

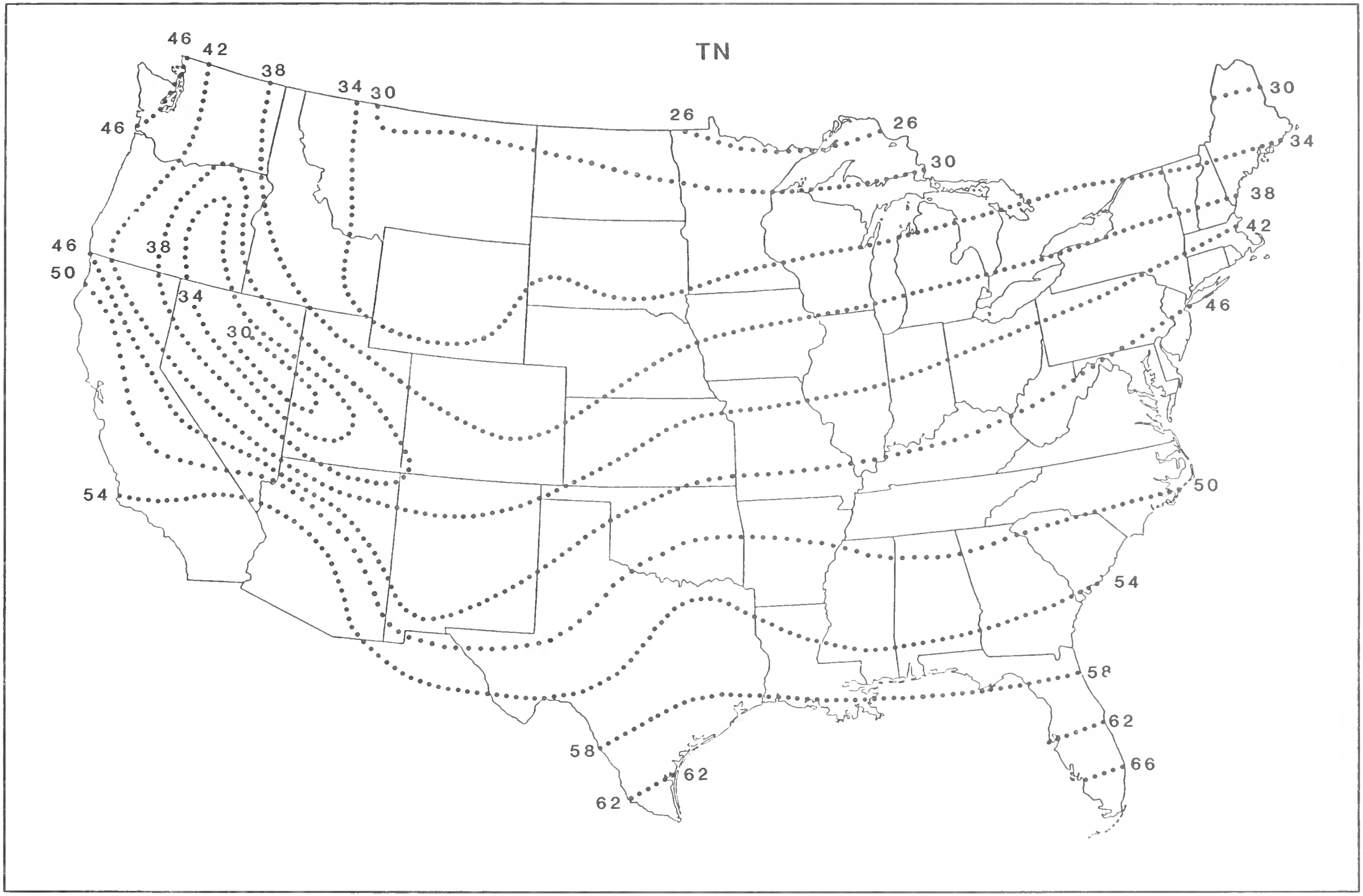

Figure A6. Distribution of the mean of t_{min} for wet or dry days (TN), °F

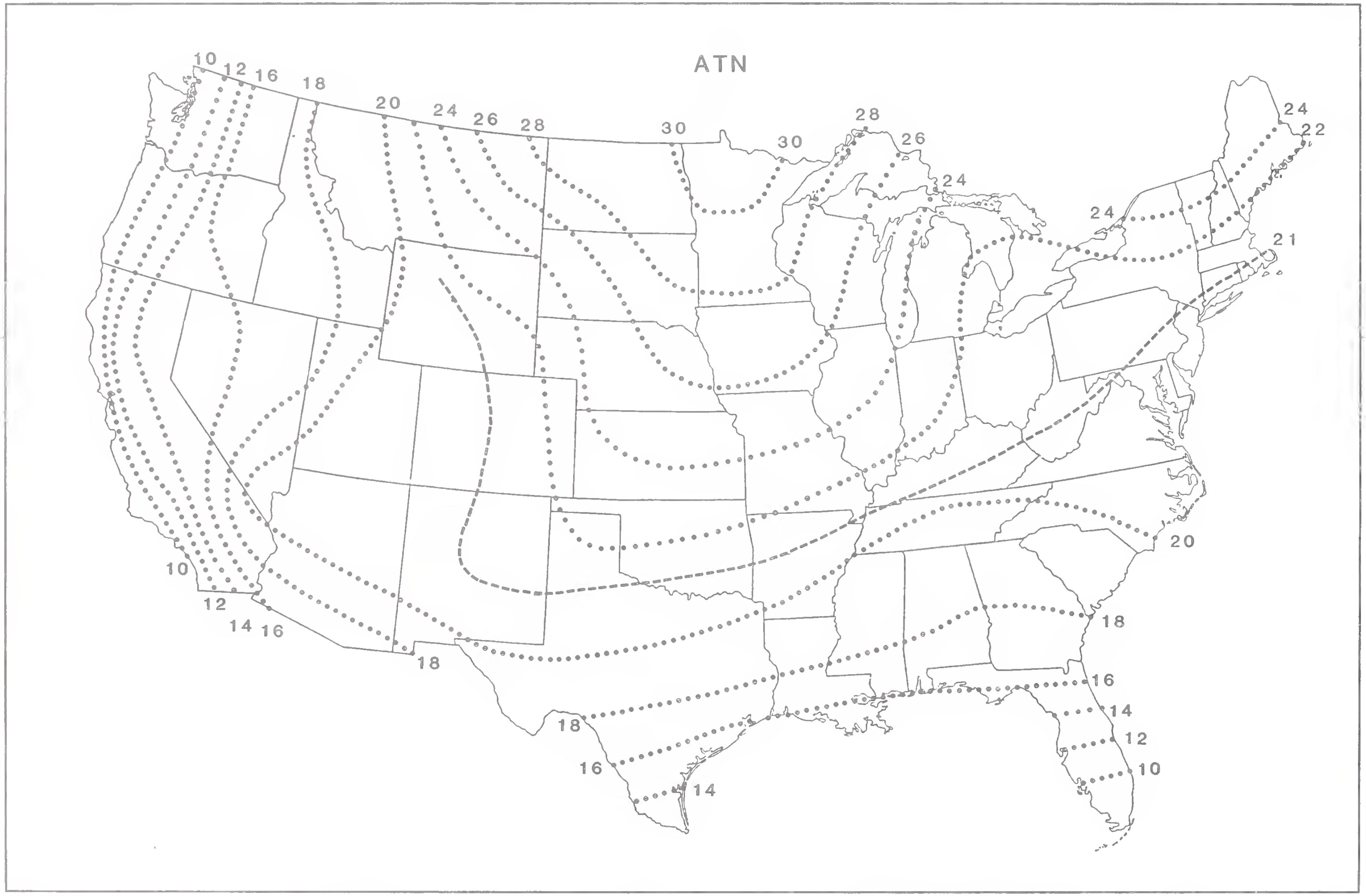

Figure A7. Distribution of the amplitude of t_{min} for wet or dry days (ATN), °F

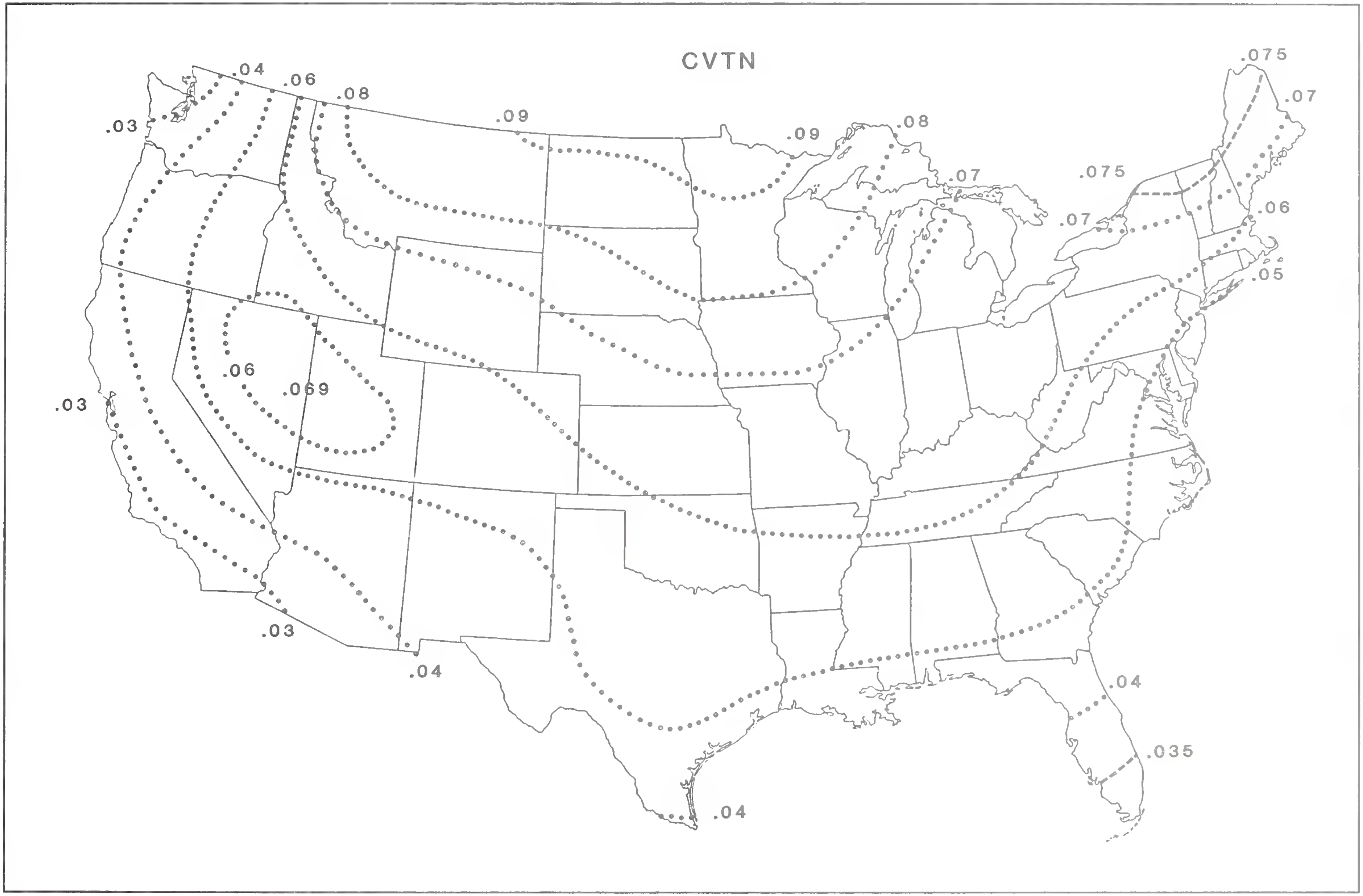

Figure A8. Distribution of the mean of the coefficient of variation of t_{min} for wet or dry days (CVTN)

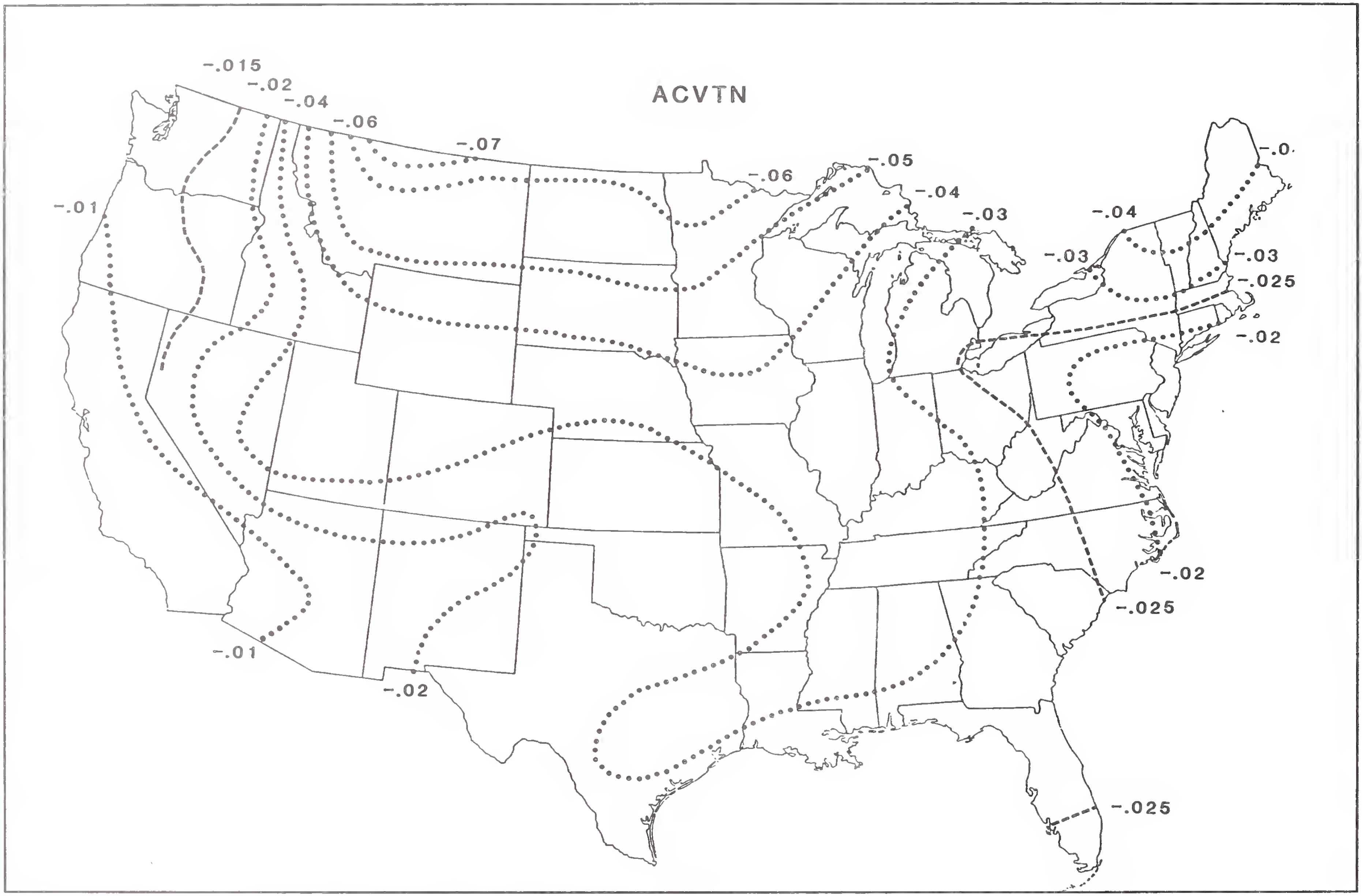

Figure A9. Distribution of the amplitude of the coefficient of variation of t_{min} for wet or dry days (ACVTN)

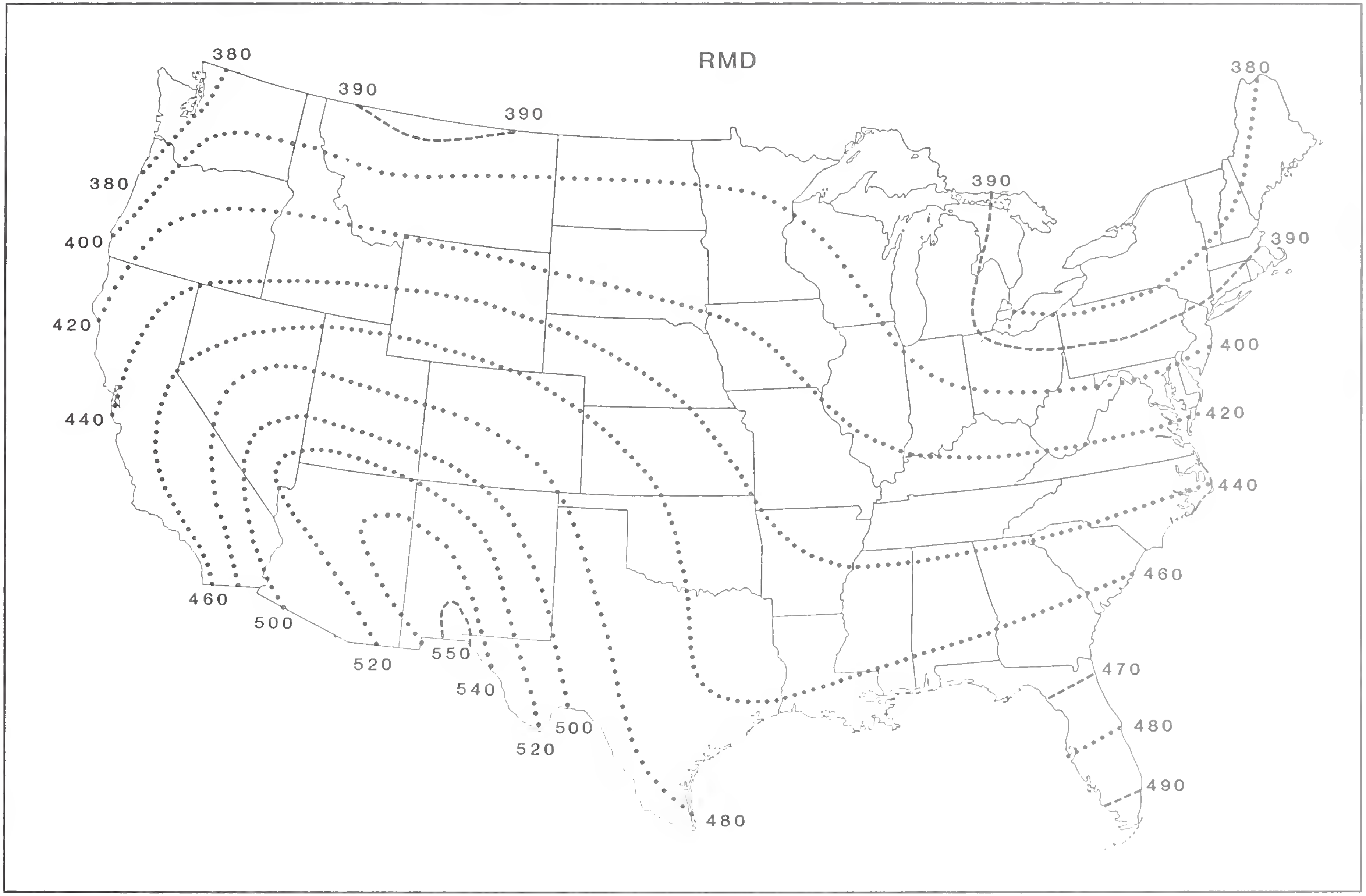

Figure A10. Distribution of the mean of r for dry days (RMD), Langleys

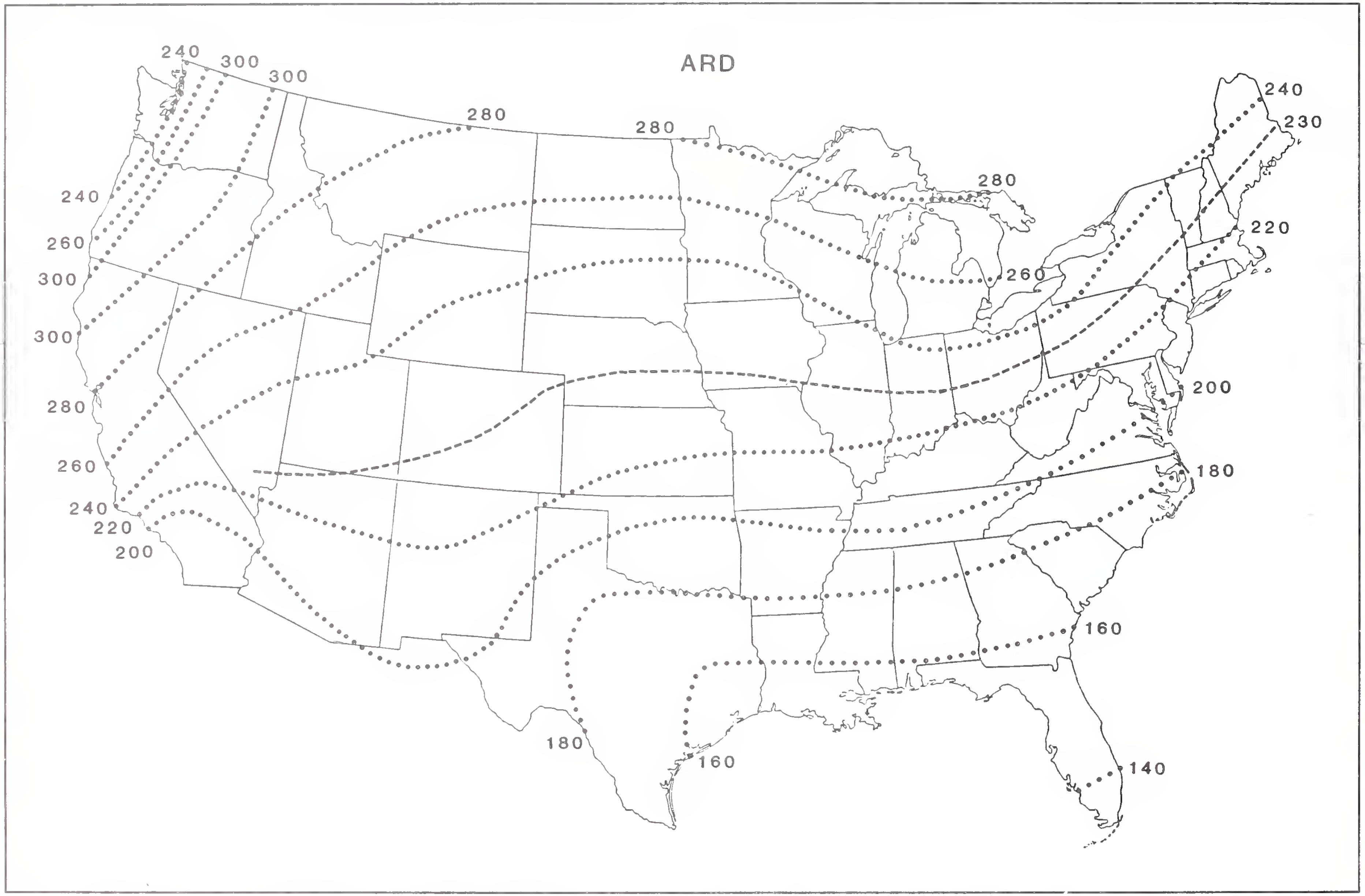

Figure A11. Distribution of the amplitude of r for dry days (ARD), Langleys

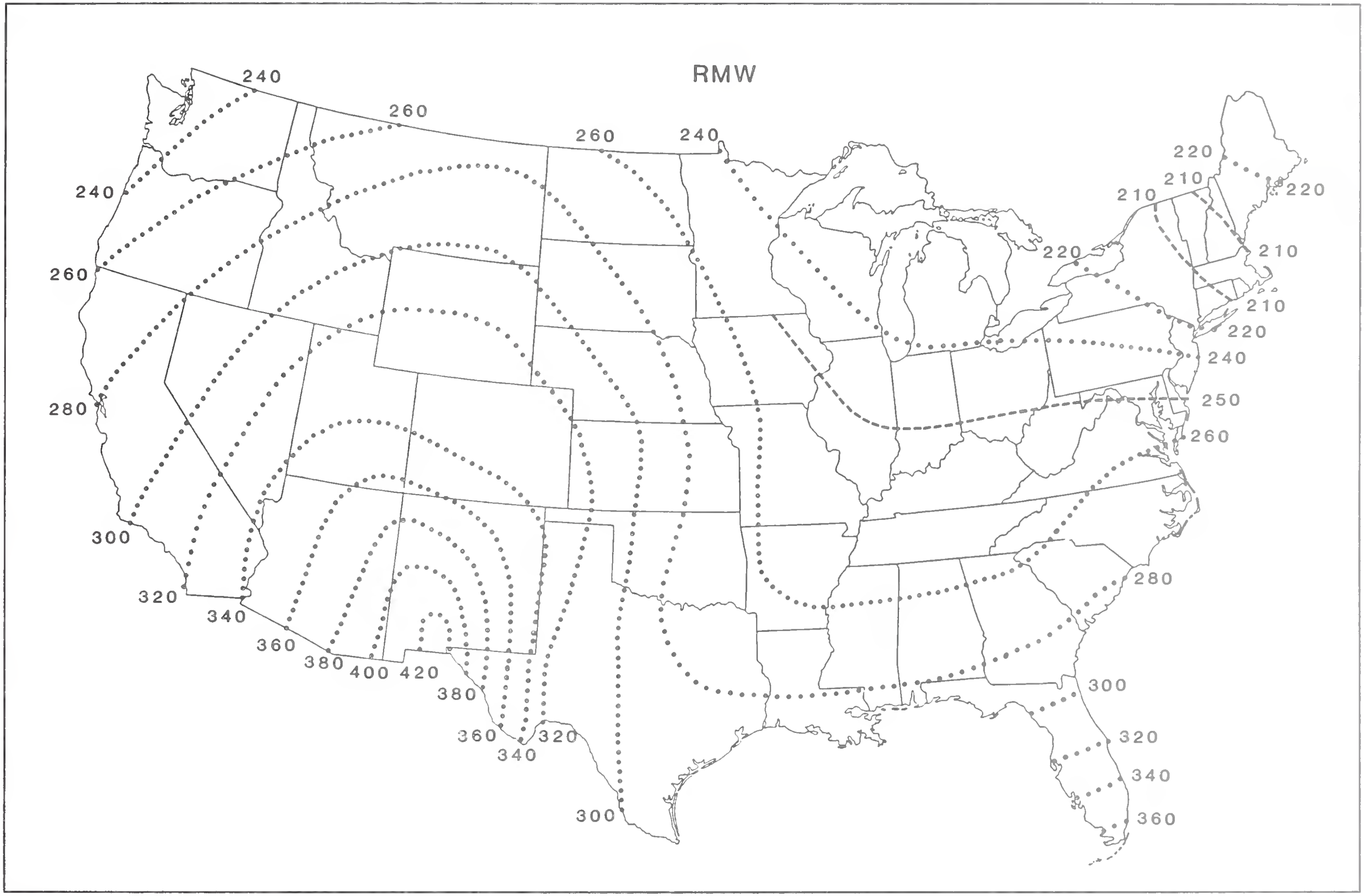

Figure A12. Distribution of the mean of r for wet days (RMW), Langleys

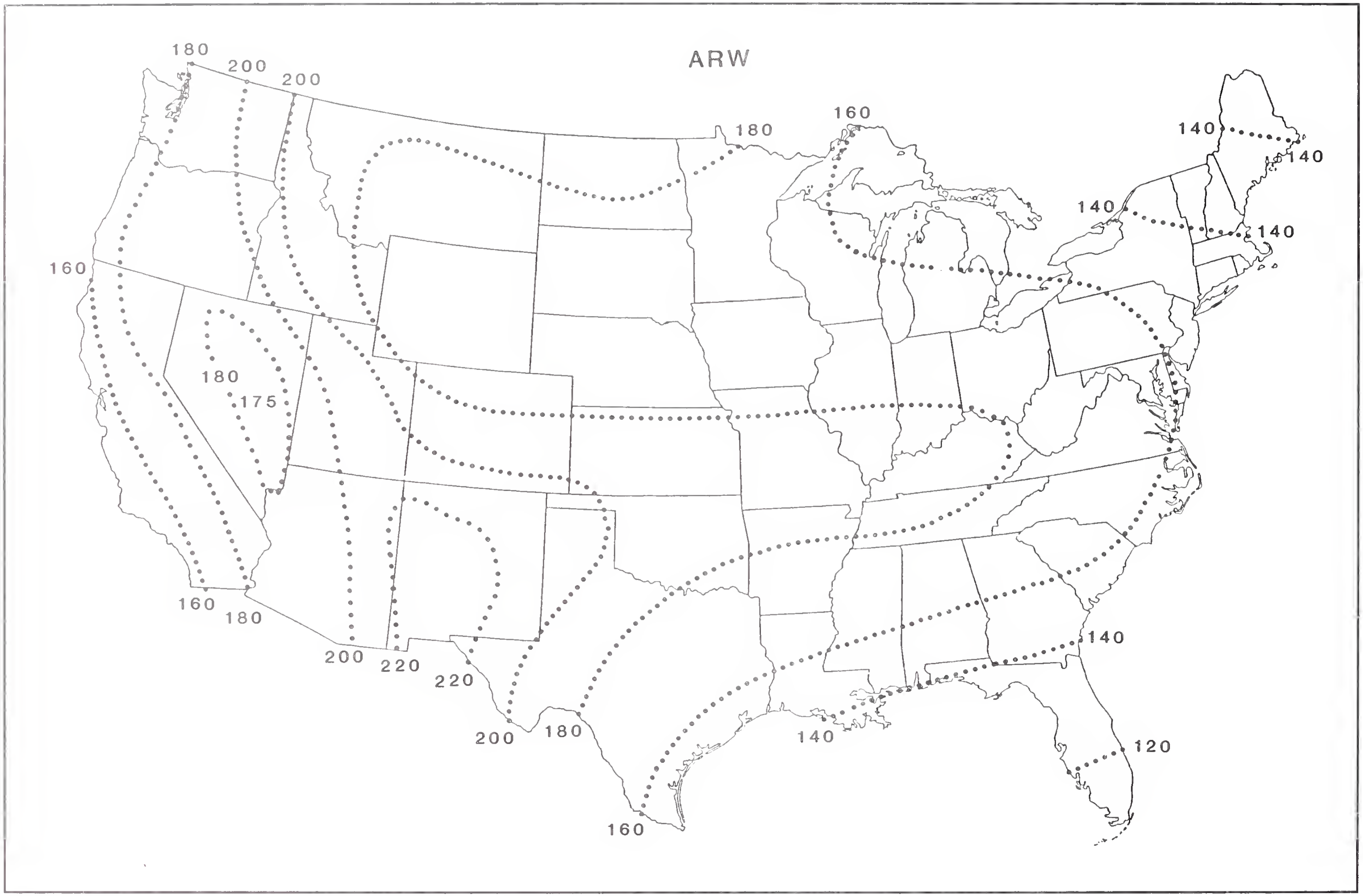

Figure A13. Distribution of the amplitude of r for wet days (ARW), Langleys

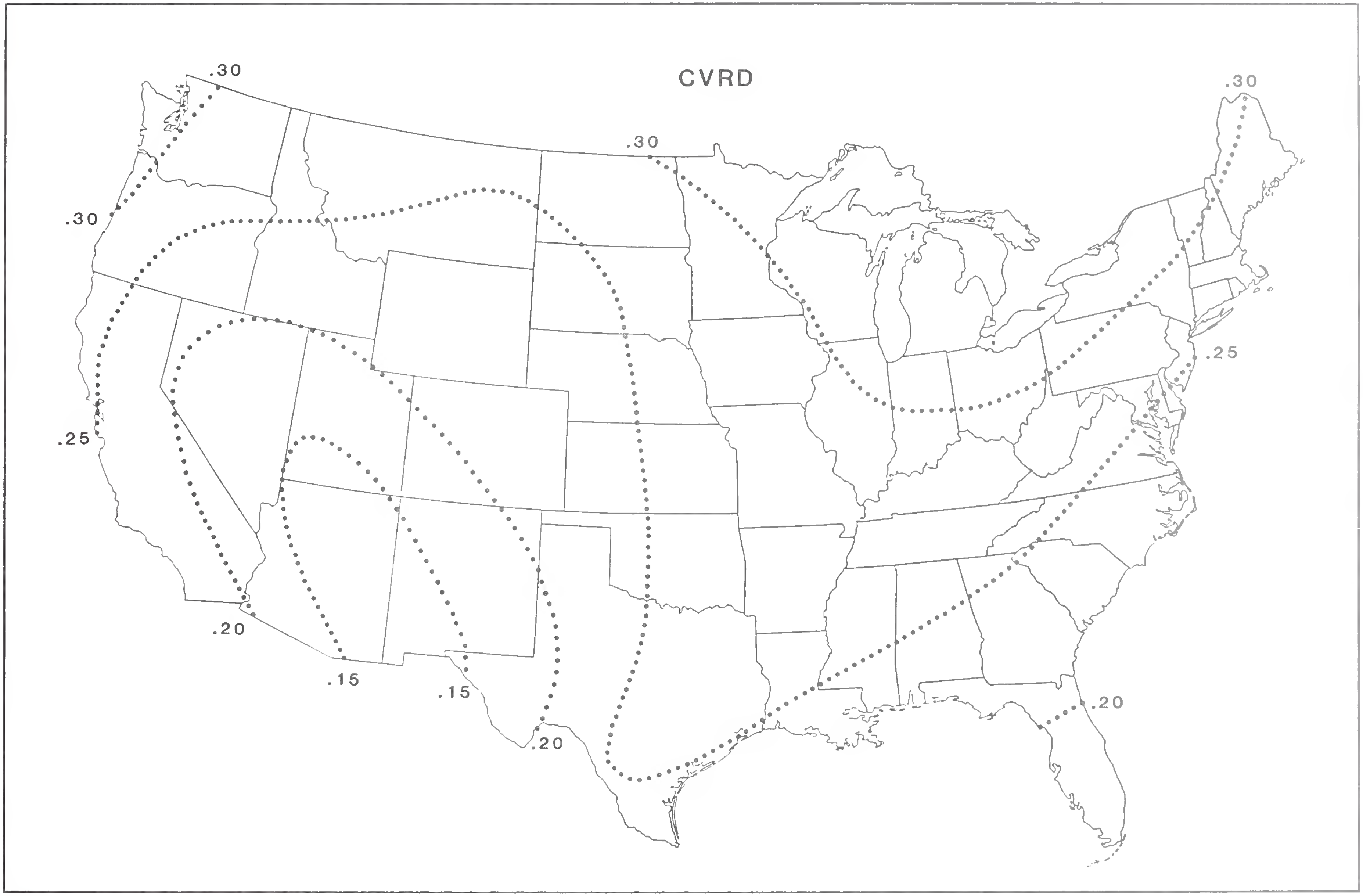

Figure A14. Distribution of the mean of the coefficient of variation of r for dry days (CVRD)

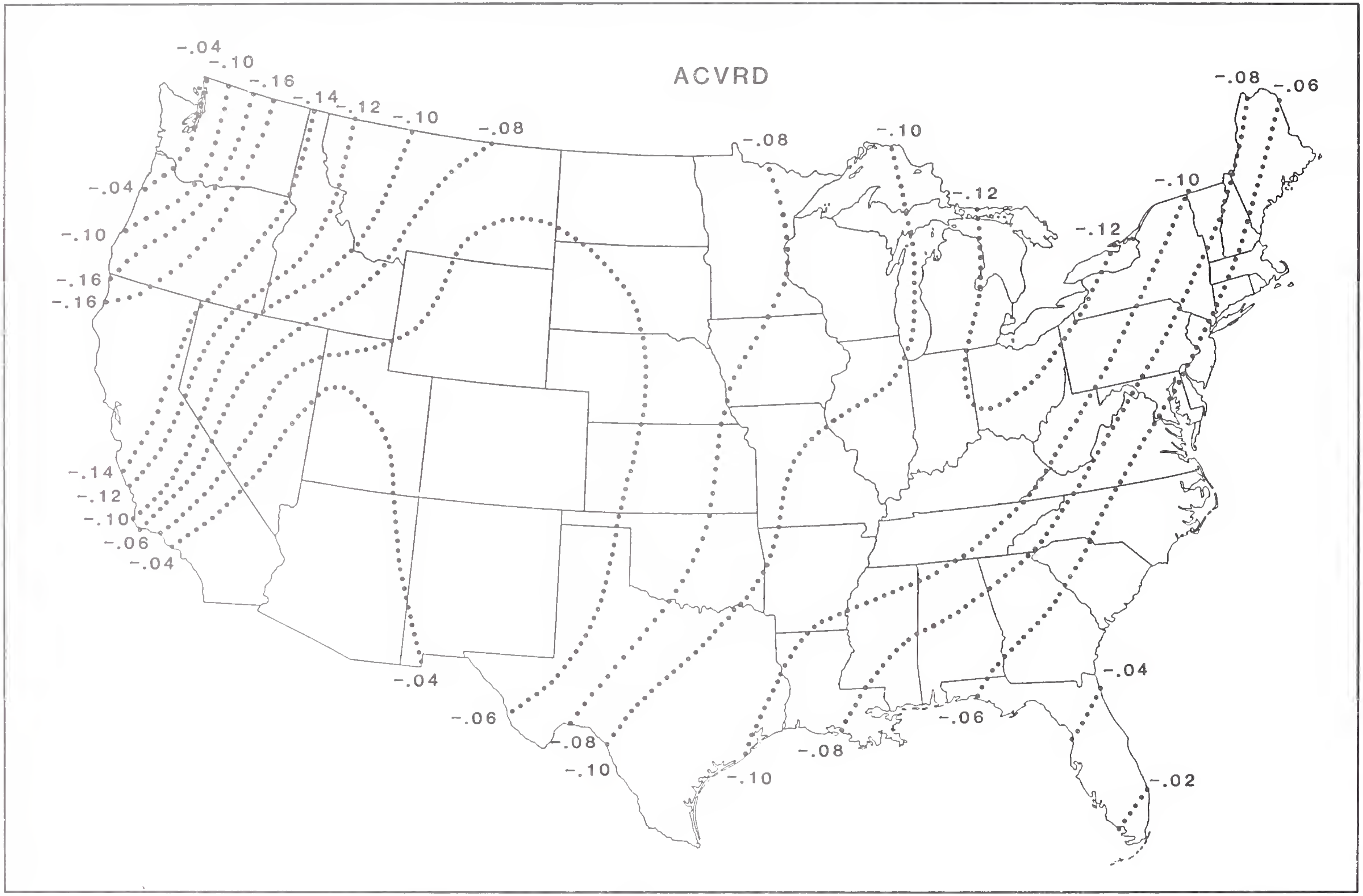

Figure A15. Distribution of the amplitude of the coefficient of variation of r for dry days (ACVRD)

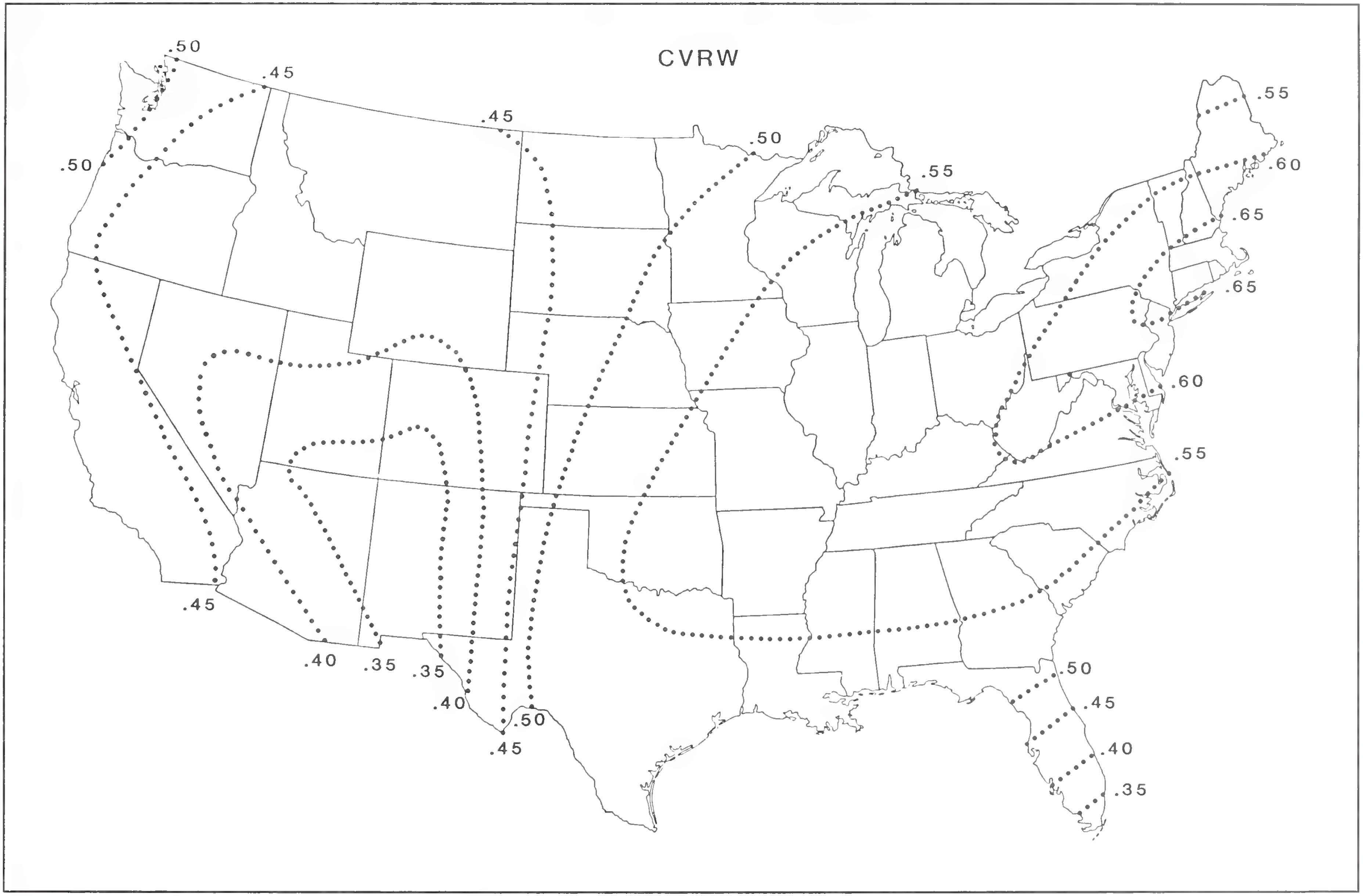

Figure A16. Distribution of the mean of the coefficient of variation of r for wet days (CVRW)

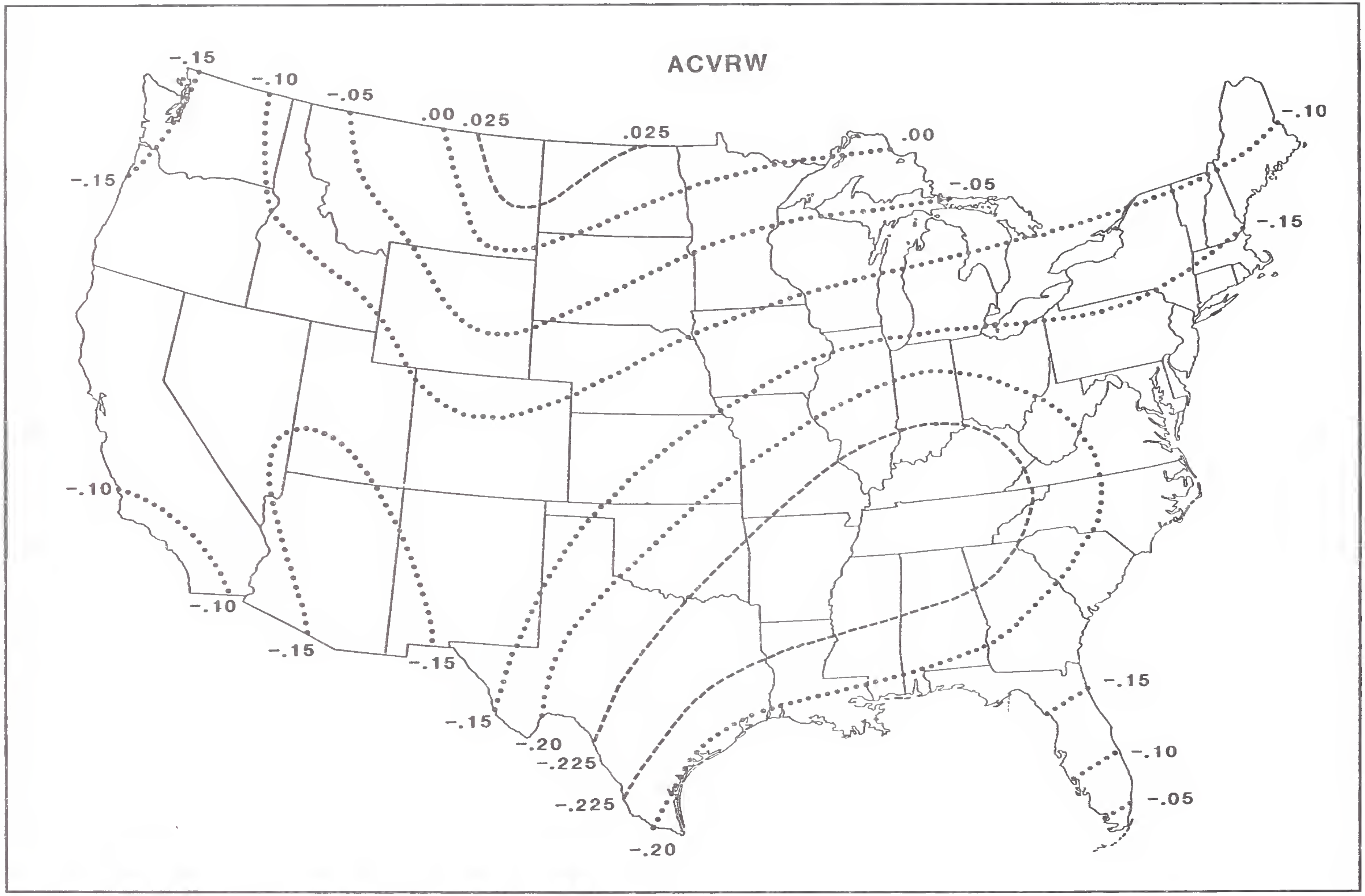

Figure A17. Distribution of the amplitude of the coefficient of variation of r for wet days (ACVRW)